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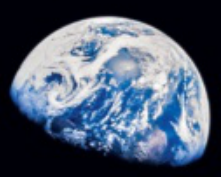
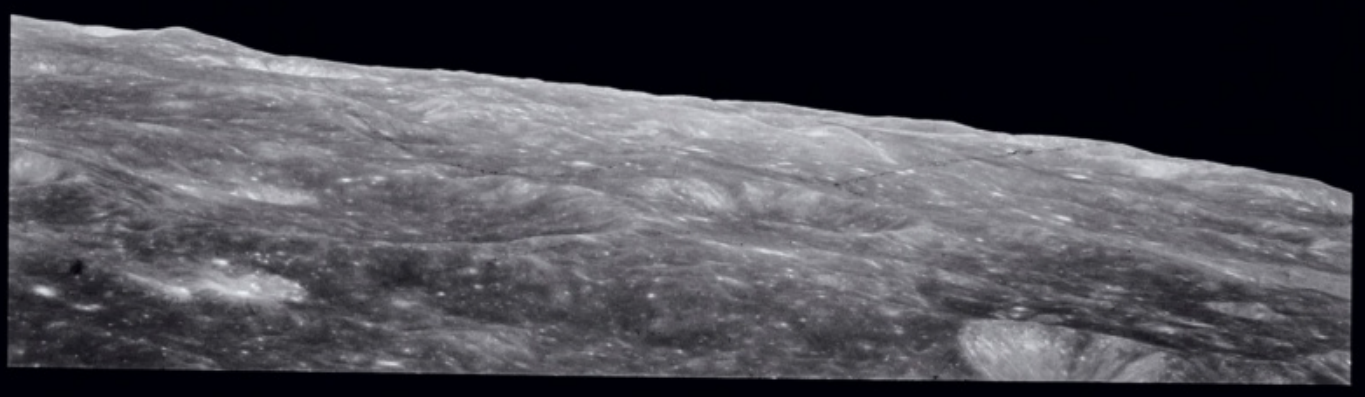
NATIONAL GEOGRAPHIC

The Moon and Beyond

A NEW ERA OF SPACE TRAVEL IS HERE





"The moon is the proving ground; Mars is the horizon goal."

JIM BRIDENSTINE
NASA ADMINISTRATOR

APOLLO 11
BUZZ
ALDRIN

THE FIRST WATCH WORN ON THE MOON

On the 50th anniversary of the first lunar landing, OMEGA is reflecting on the golden moments that defined that iconic day. Nobody remembers it quite like Buzz Aldrin, who wore an OMEGA Speedmaster when he stepped onto the dusty surface and left his footprints in history.

#MOONWATCH

OMEGA

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Shot on OnePlus
Powered by Triple Camera

INSPIRED BY NATURE

What is the best way to challenge the creativity of some of the world's most talented photographers - while at the same time pushing a new smartphone to the limits of its design specs?

The answer is to give three of these individuals a OnePlus 7 Pro and unleash them in numerous locales across the United States so they can immortalize the theme – **Inspired by Nature.**

Their brief was simple: to capture as much of the rugged natural beauty of a rich and unimaginably diverse continent – and how people interact with it - as they could in seven days.

With their creativity and imaginations unleashed they journeyed forth to tell the stories of their chosen regions.

Their treks ranged from cloud and snow-capped mountains, to meadows bedecked with wildflowers, to ancient deserts, to warm tropical waters.

And so they fanned out from coast to coast: the iconic American west for Australian Krystle Wright, the wonders of California for Andy Bardon and the Sunshine State for Florida native Carlton Ward Jr.

All of the photographers succeeded in capturing the distilled essence of America's geographical diversity and the delicate balance between the natural and human environment.

Look out for the stunning 40-page magazine available with the July edition of *National Geographic* magazine.

NATIONAL GEOGRAPHIC ONEPLUS

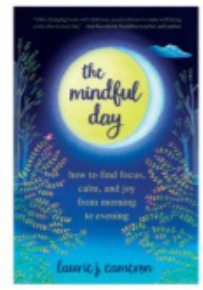
This content was produced in partnership with OnePlus.

Left: *An aerial perspective of a coastal environment on the Northern California Coast.* ***Photo credit*** *Andy Bardon.*
Above: *Exposed mangrove roots in Biscayne Bay, Florida.* ***Photo credit*** *Carlton Ward Jr.* **All #ShotonOnePlus**

NAT GEO FILMS

Apollo: Missions to the Moon takes viewers along

To mark the 50th anniversary of the first crewed lunar landing, National Geographic brings NASA's Apollo space program to life with the two-hour documentary *Apollo: Missions to the Moon*. The film combines archival TV footage, never before heard radio broadcasts, home movies, NASA film, and Mission Control audio to create a riveting, you-are-there experience. Kicking off a multi-night television event, *Apollo* will air at 9/8c on July 7 on National Geographic.



BOOKS

Experience *The Mindful Day*

Meditation expert Laurie Cameron offers practical advice on integrating mindfulness into busy lives. *The Mindful Day,* now in paperback, is available wherever books are sold and at *shopng.com/books*.

TELEVISION

A return visit to *Yellowstone Live*

This four-night event follows cinematographers in real time as they explore an iconic American wilderness and showcase its denizens. Season two of *Yellowstone Live* will air June 23-26 at 9/8c, on Nat Geo WILD and National Geographic.

NAT GEO WILD

Howie Mandel hosts wacky animal series

Take some of the funniest animal videos on Instagram, add a veteran comic to narrate—and you've got season two of *Howie Mandel's Animals Doing Things*. Episodes air Saturday nights at 9 and 9:30 starting June 15 on Nat Geo WILD.

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PHOTO: NASA

You were
born
to

explore

the
universe.

The stars and planets called out to us to touch the limits of our galaxy. 50 years ago we answered that call for the first time. Astronauts walked on the moon and when they returned we invented cell phones, cable TV, solar cells, wireless headphones, 3D printing... What will we invent when astronauts return from Mars?

There's only one way to find out.
We're going back to space.

The Red Planet is waiting for us but we all must work together. We need astronauts to fly, but we need engineers to build. We need roboticists to program the rovers, and we need everyone... We need *you*, to share your love of space with others. What will your role be?

The greatest gift each generation leaves the next are the mysteries they were unable to solve because we will find the answers. It's our time – as people, as countries, as a PLANET, to fling ourselves into the greatest adventure humanity has ever known.

LET'S GO

#LEGOletsgo

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PRISTINE SEAS

Preserving Earth's Undersea Treasures

BY **SUSAN GOLDBERG** PHOTOGRAPH BY **REBECCA HALE**

In 2018 National Geographic Explorer-in-Residence Enric Sala led a Pristine Seas diving expedition at Tierra del Fuego, Argentina. The expedition's research laid the scientific groundwork for setting aside a protected marine park there.

'FIVE PERCENT OF THE OCEAN IS PROTECTED. SCIENCE SAYS HALF THE OCEAN MUST BE PROTECTED TO MAKE A REAL DIFFERENCE.'

ENRIC SALA has made it his mission to save wildlife and habitat. In the past 10 years alone, thanks to his efforts and partnerships with governments around the world, an area half the size of Canada has been protected from all manner of human exploitation.

The reserves that marine ecologist Sala has helped establish aren't on land but in the oceans. His Pristine Seas project, sponsored by the National Geographic Society, has been instrumental in getting more than two million square miles set aside—keeping untouched wild areas healthy and giving depleted ones a chance to recover.

Sala's article this month recounts how Pristine Seas lent support to the creation of a protected marine park at the tip of Argentina. It's next to waters that Chile designated as a park, and Sala believes it's the largest contiguous transboundary protected ocean area in the world. Yet it's not nearly enough. "Five percent of the ocean is protected," he told me during a recent visit. "Science says half the ocean must be protected to make a real difference."

Of all the reserves he's worked on, I asked Sala, which one does he like the best? "That's like asking which of your sons or daughters you love the most," he complained. But, he conceded, "there is one place: the Southern Line Islands, the most pristine archipelago in the Pacific. There, in 2016, we saw the greatest El Niño year ever, and half the corals bleached and died."

His team's going back this year to see if the area has recovered. If it has, he says, "it will give us hope"—an essential commodity as Sala and his collaborators press on to protect more ocean life.

Thank you for reading *National Geographic*.

GREET THE WORLD'S WONDERS

TRAVEL WITH NATIONAL GEOGRAPHIC

NATIONAL GEOGRAPHIC

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Machu Picchu, the Great Barrier Reef, Cape Town, the northern lights: whichever wonder calls you, National Geographic can get you there—and give you a close-up view. Our private expeditions are for just you and the travelling companions you choose, so you can experience incredible places, exploring with private guides and enjoying the freedom to tailor your trip to your own interests.

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When you travel with us, you help further the work of our scientists, explorers, and educators around the world. Every year, we distribute a portion of our proceeds to the National Geographic Society, creating more opportunities to work toward a planet in balance. Learn more at natgeo.com/giveback.

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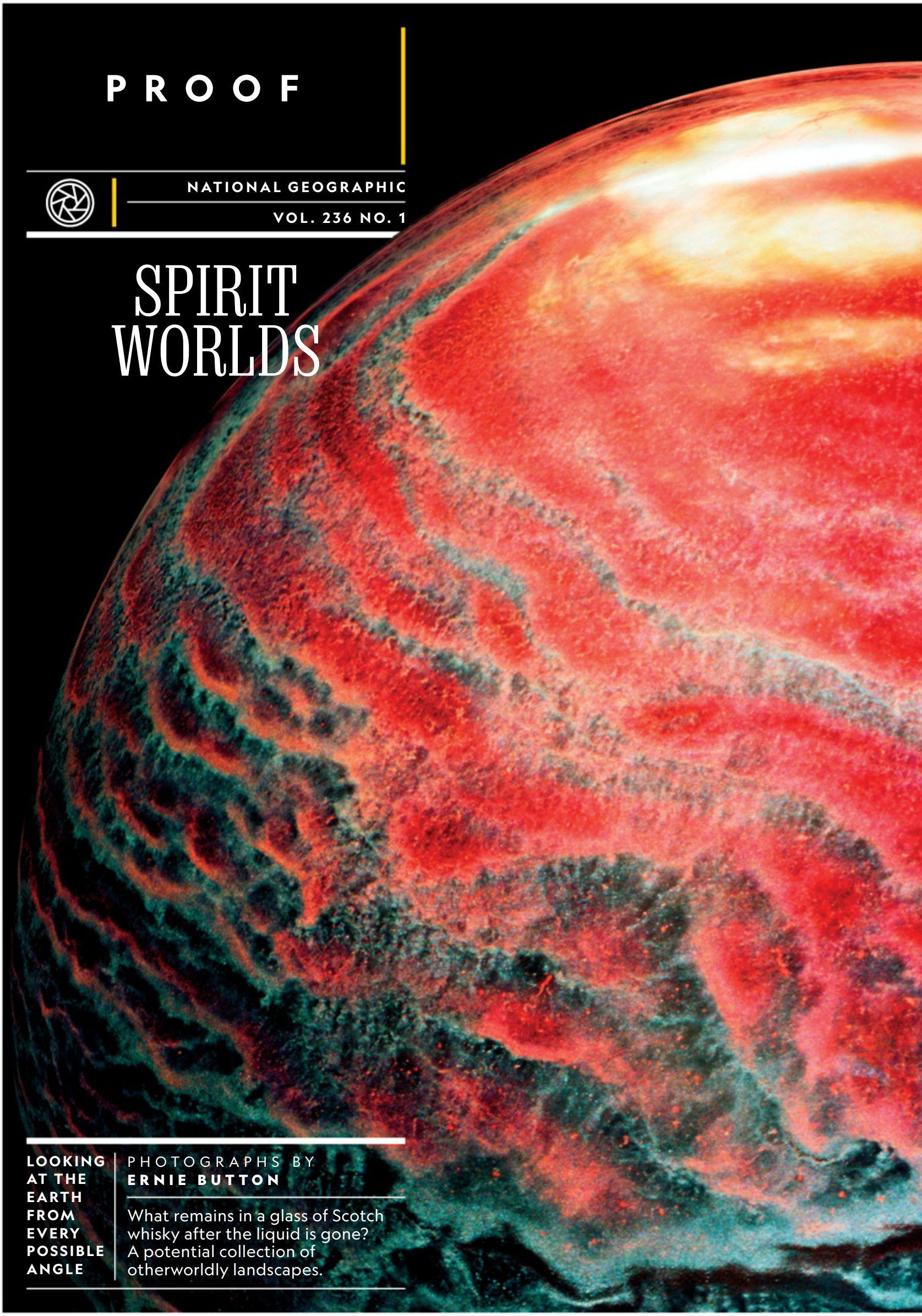
PROOF

NATIONAL GEOGRAPHIC
VOL. 236 NO. 1

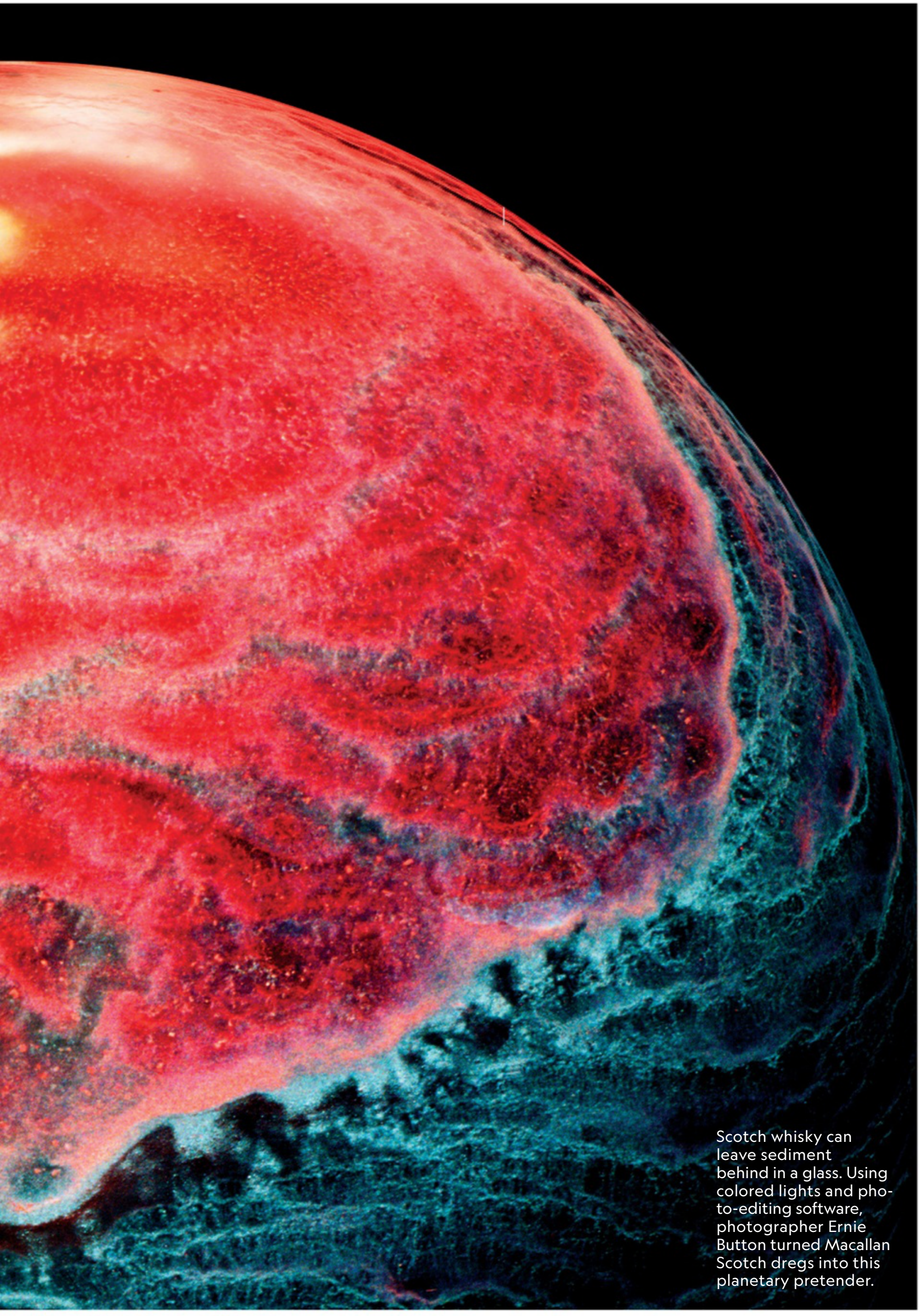
SPIRIT WORLDS



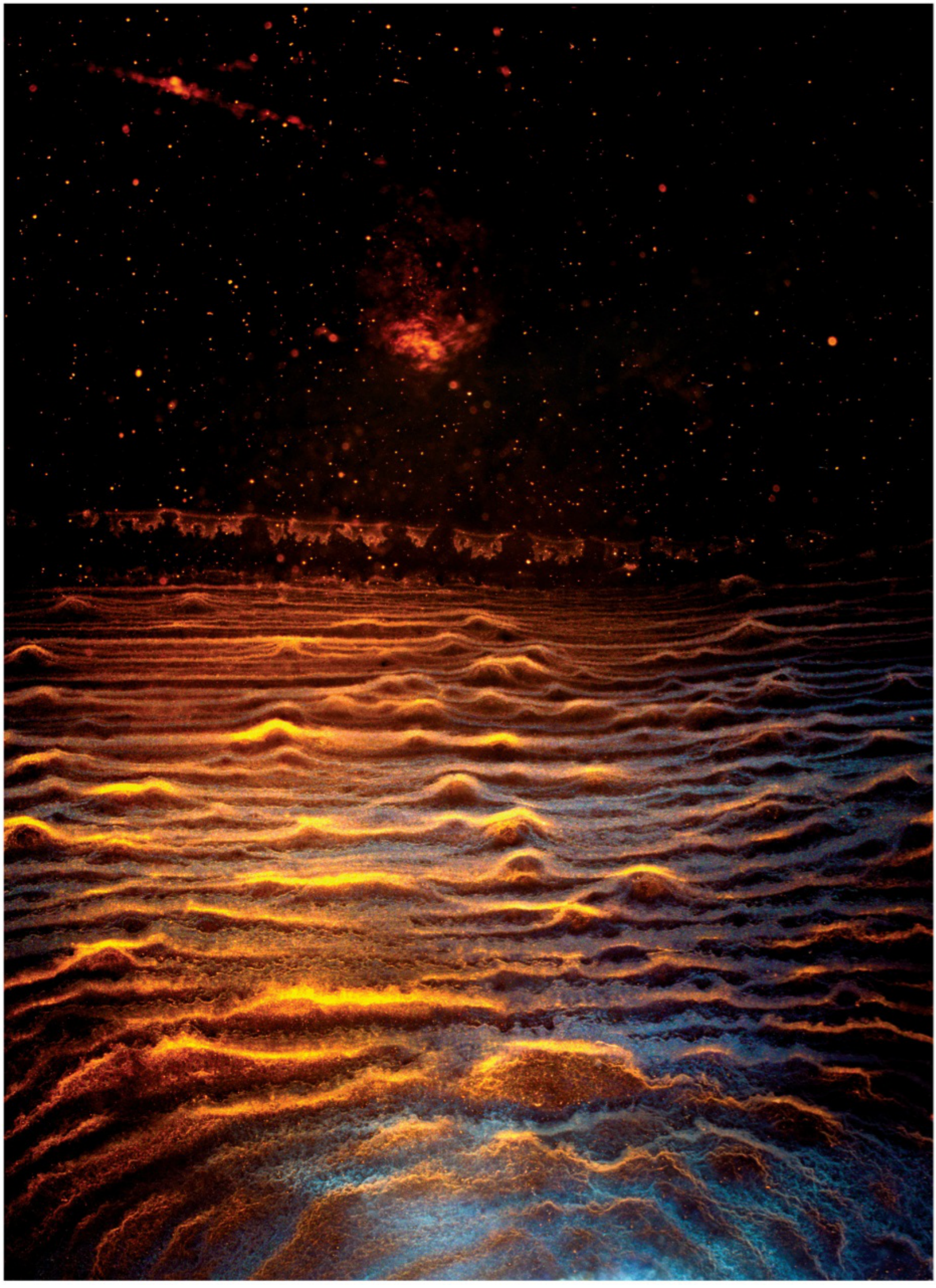
LOOKING AT THE EARTH FROM EVERY POSSIBLE ANGLE

PHOTOGRAPHS BY
ERNIE BUTTON

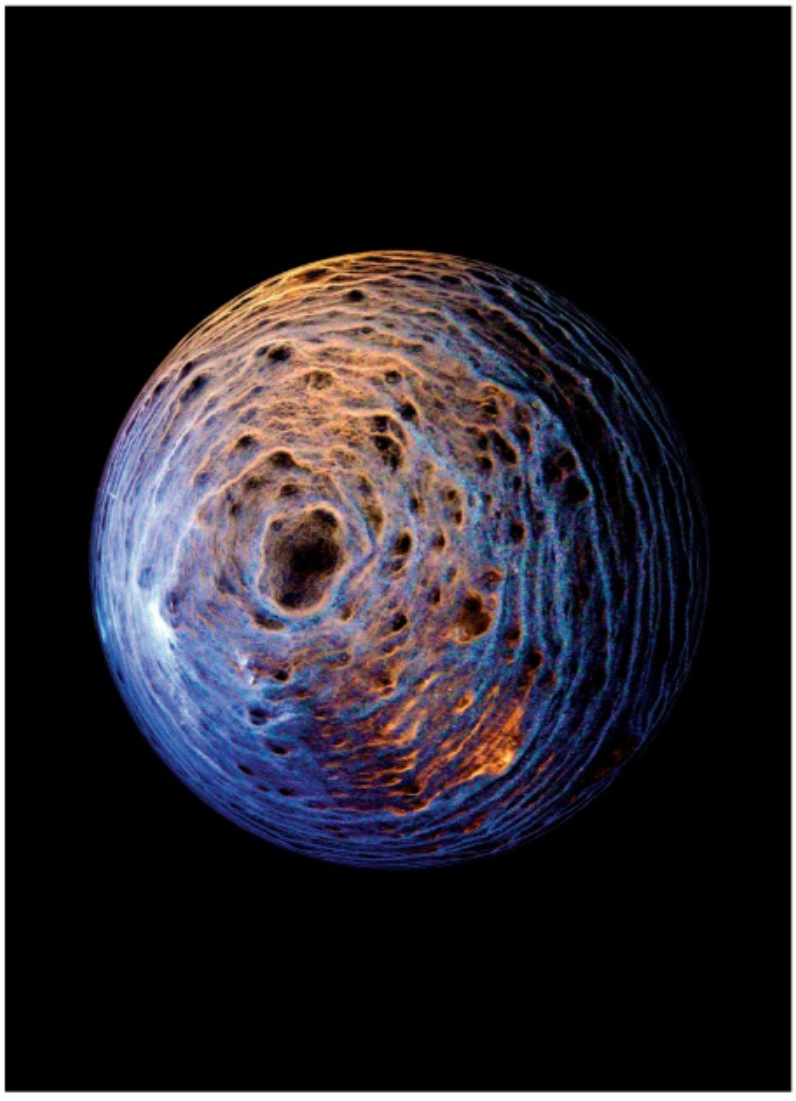
What remains in a glass of Scotch whisky after the liquid is gone? A potential collection of otherworldly landscapes.

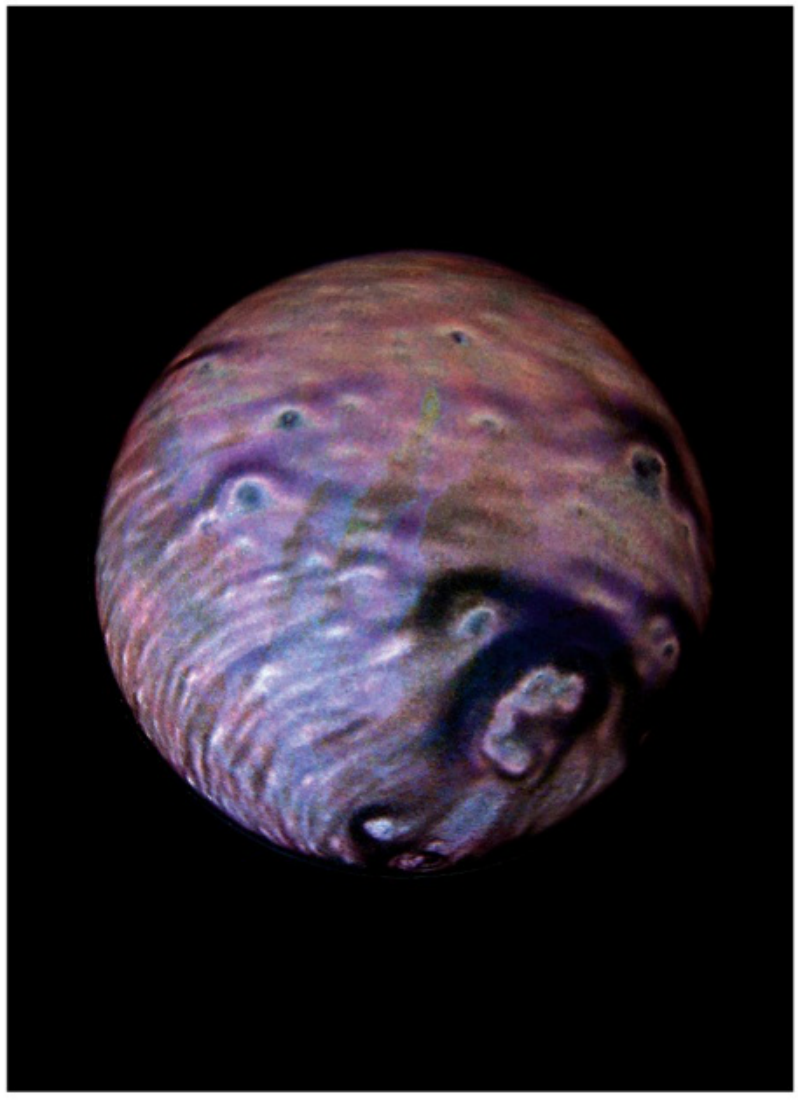


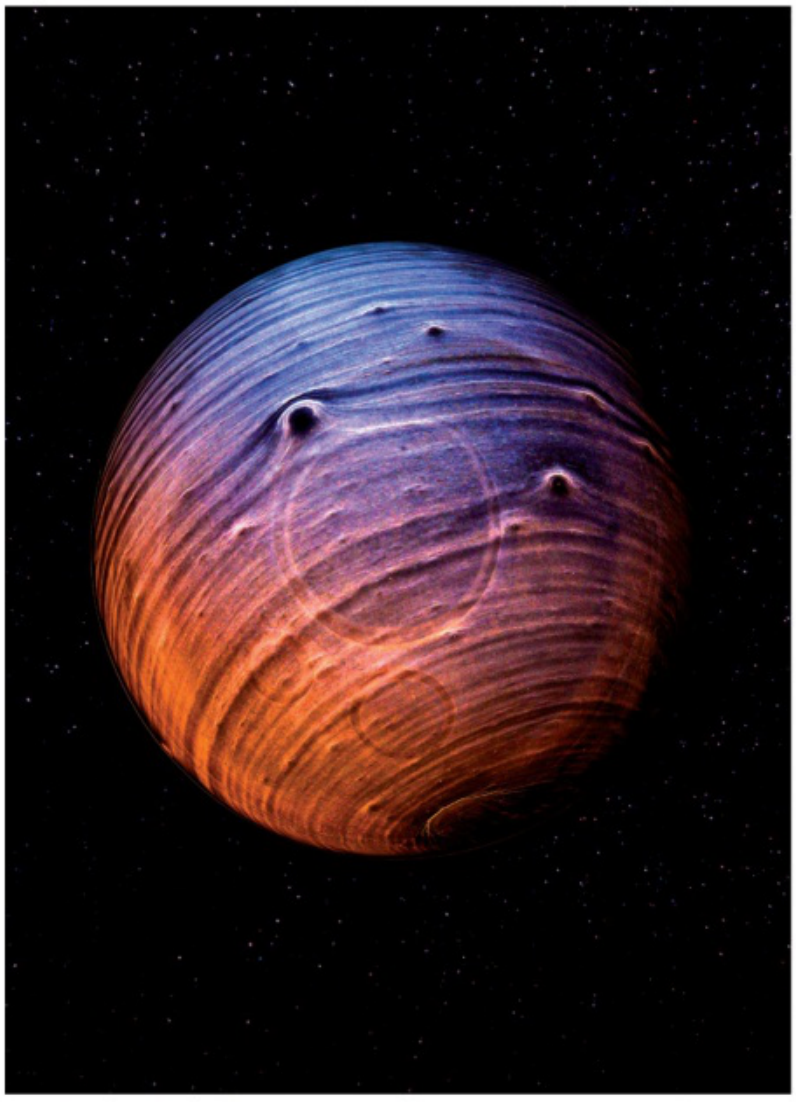
Scotch whisky can leave sediment behind in a glass. Using colored lights and photo-editing software, photographer Ernie Button turned Macallan Scotch dregs into this planetary pretender.



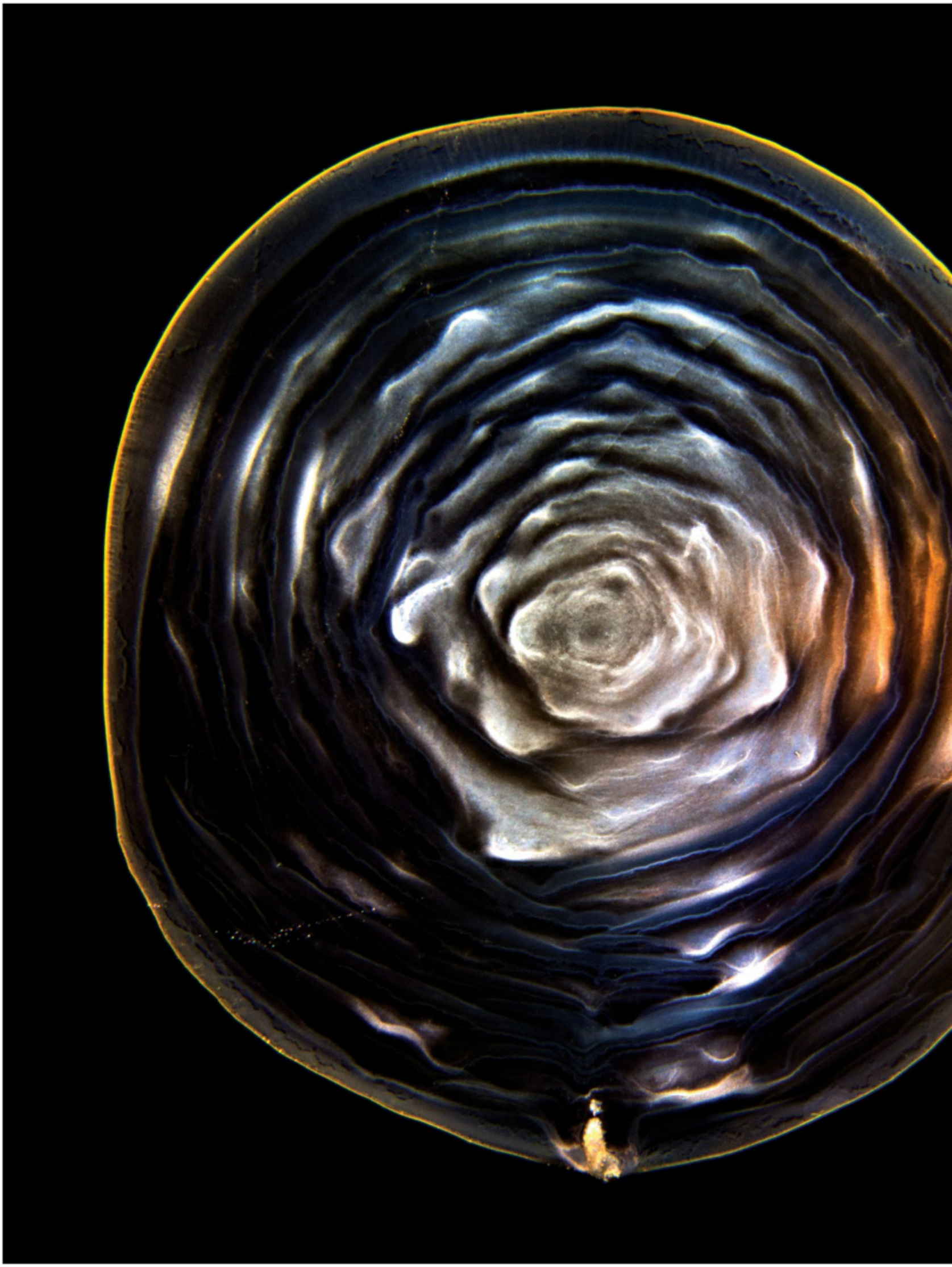
Residue from the barrels in which distillates were aged forms lavalike waves in a glass that held Glenlivet Scotch. Button created different effects with tools including colored lights and editing software.



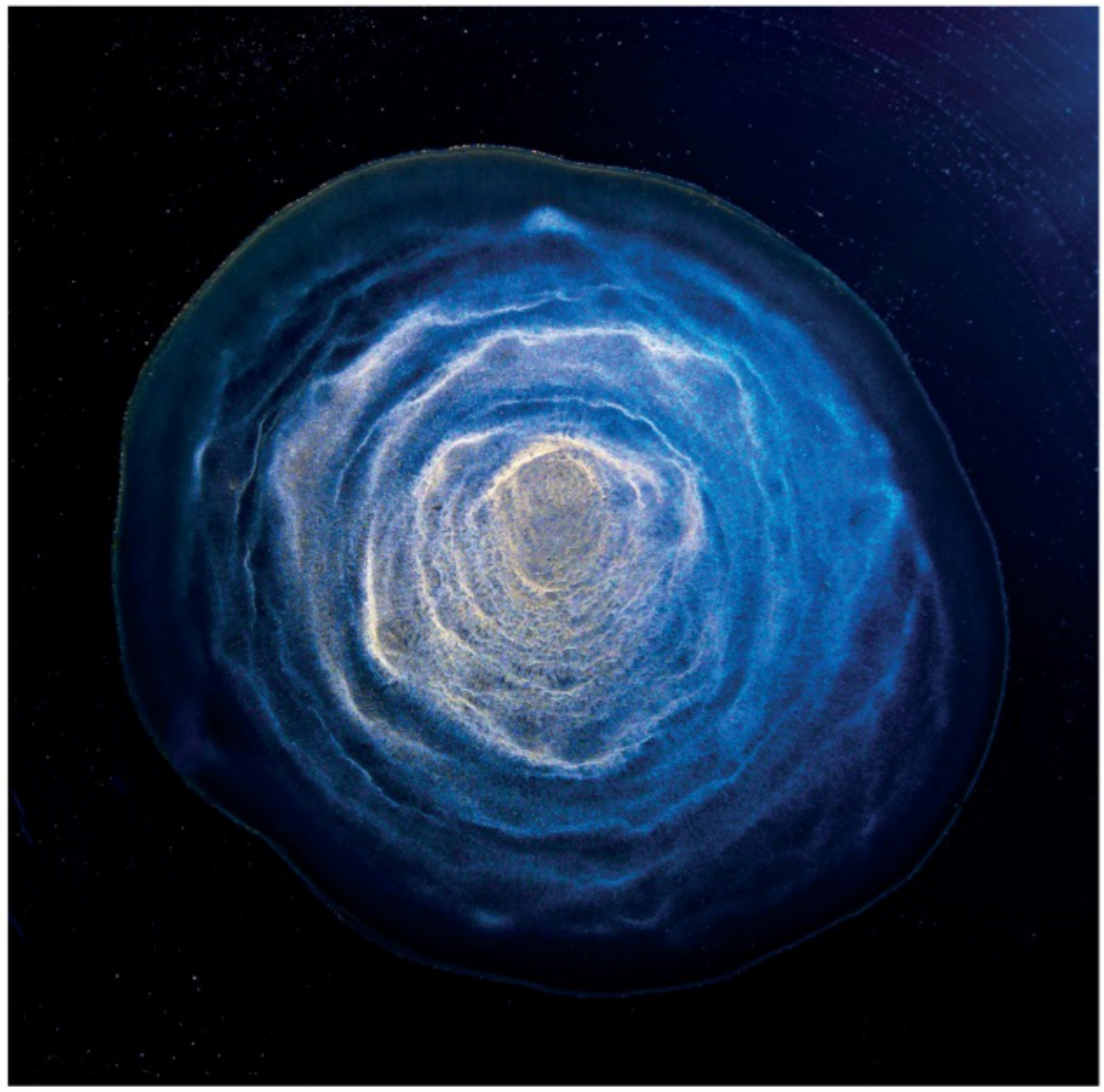


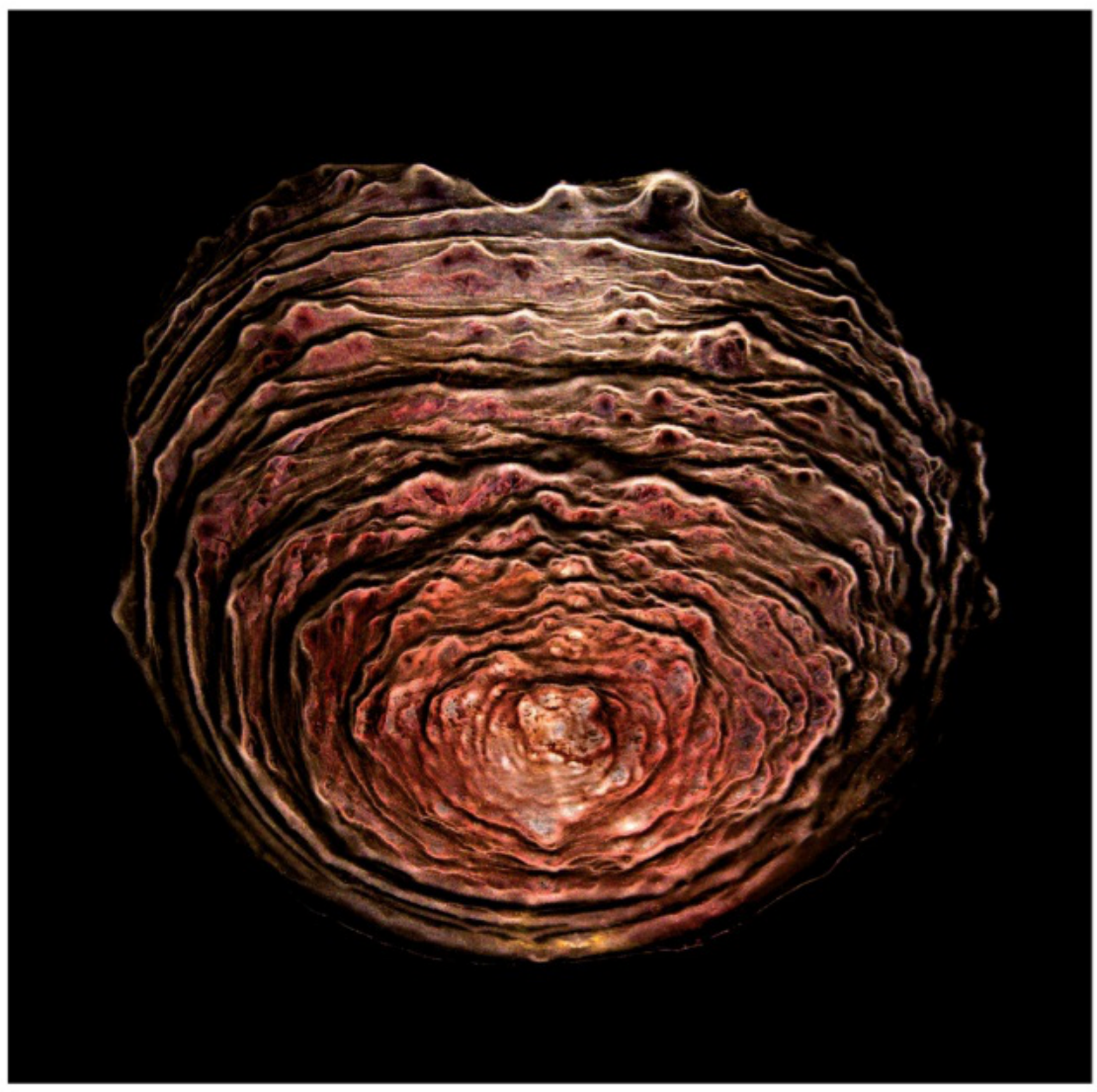


Button shot sediment from Balvenie, Macallan, Macallan, and Glenfiddich whiskies (clockwise from top left). Then, using Photoshop, he shaped some images to resemble celestial bodies.



Particulate forms a blossom-like vortex in a glass that held Macallan, a single malt Scotch whisky produced according to strict regulations in Scotland. (Whiskey spelled with an *e* is produced elsewhere.)





Button photographs sediment patterns that appear naturally. His creativity comes out in the lighting, which can make remnants of Macallan (top) or Glenfiddich appear nebulous or richly metallic.

THE BACK STORY

THE DREGS OF A FINISHED GLASS OF SCOTCH WHISKY CAN YIELD WILD CELESTIAL SCENES.

WASHING DISHES—the most ordinary of chores—led photographer Ernie Button on a decadelong discovery of a fantasy universe. While placing an empty whisky glass in the dishwasher, he noticed at the bottom a thin residue of evaporated alcohol—specifically, Scotch, the term for a whisky aged more than three years in oak barrels in Scotland. When the last drops of alcohol dried up, they left sediment from the whisky's distillates. Button took the glass to his studio, laid it on its side, and took pictures.

The whisky-sediment patterns are like snowflakes; each has a unique design. They all, however, are light gray until Button lights them with multicolored lamps. The gray lines and swirls spring to life and make the rich designs resemble colorful landscapes of planets and moons. "I think of it as drinks and a show," he says. Through trial and error, Button found that only Scotch whiskies accumulate enough sediment. The oldest he's photographed is a 25-year-old whisky. (Verdict: no big difference.)

In contrast to photographers who shoot epic scenes in exotic locales, Button looks inward and stays local. Before photographing spirits, he created landscapes with breakfast cereal boxes and chronicled the disappearance of coin-operated rides at grocery stores. Button's work proves there are wild things to be observed in everyday life, even in dirty dishes. **—DANIEL STONE**

"You just have to look closely" at the bottom of a whisky glass, says photographer Ernie Button.

THE DISCOVERIES OF TODAY THAT WILL DEFINE THE WORLD OF TOMORROW

NATIONAL GEOGRAPHIC | VOL. 236 NO. 1

Let's Send Only Women to Space

PHYSICALLY AND PSYCHOLOGICALLY, FEMALES HAVE THE RIGHT STUFF FOR LENGTHY MISSIONS IN SPACE. SO WHY SEND MALES AT ALL?

BY **NADIA DRAKE**

IF YOU'RE PACKING for an interplanetary space mission—one that's very long and might involve populating a faraway world—sending an all-female astronaut crew could be an intelligent choice.

Before you raise an eyebrow at the prospect, remember that NASA recruited and flew only all-male crews for decades. In fact, in the 58 years that Earthlings have launched humans into orbit, about 11 percent of them—63 individuals—have been women.

"An all-female mission tends to be something that NASA has avoided in assignments because it seems like a stunt," says Margaret Weitekamp, a curator at the National Air and Space Museum. But in some ways, women are potentially better suited for space travel than men.

Let's focus on four factors. Women are generally smaller. Women suffer less from some problematic physical effects of spaceflight. Women have some personality traits more innately suited for long-duration

IF YOU'RE AIMING FOR MARS—OR THE STARS!—THE CONTRAST BETWEEN SENDING ENOUGH FOOD FOR A LARGE MAN VERSUS A SMALL WOMAN COULD END UP BEING SUBSTANTIAL.

missions. And last but hardly least: Populating another world requires reproduction, and so far that isn't possible without biological women, whereas men's contributions can be... well, more on that later.

FIRST, THE WEIGHT ADVANTAGE. Sending lighter humans into space is just plain smart because rocketing weight into space, and maneuvering once you're there, requires fuel, which costs money. "Some of us have speculated for years that having an all-female crew—or at least a crew of smaller individuals—would be advantageous from the total-mission-weight standpoint," says Wayne Hale, former NASA engineer and space shuttle program manager.

Sending six smaller women into space for months or years could be significantly less expensive than sending six burly dudes, and lower body weights are just a small part of it. The rest of the difference comes from the amount of food, oxygen, and other resources needed to keep smaller humans alive. For a short-duration trip, the difference might be negligible. But if you're aiming for Mars—or the stars!—the contrast between sending enough food for a large man versus a small woman could end up being substantial because, on average, men require 15 to 25 percent more calories a day than women.

It's a difference that Kate Greene observed in 2013 while participating in a four-month-long simulated mission in a Mars habitat. Part of Greene's assignment was to monitor the metabolic output of her crewmates—and on average, she reported, females expended less than half the calories of their male counterparts, despite similar activity levels.

On top of that, smaller people produce less waste (think carbon dioxide and other bodily excretions), which translates to lower demands on spacecraft systems designed to recycle and remove that junk.

So why not simply launch a crew of small humans, sexes be damned? Because human bodies respond differently to spaceflight, and though the data are relatively sparse—again, women haven't flown much in space—it does seem that women's bodies may have a slight edge in tolerating spaceflight's effects.

ABOVE EARTH'S PROTECTIVE magnetic shield, exposure to damaging radiation occurs more quickly, causing an increased risk of cancer and other issues. Also, funky things happen in microgravity, where neither cells nor entire bodies can sense

Gender, sex, and space

For this discussion of who is sent into space, let's define our terms as NASA did. In a research report titled "The Impact of Sex and Gender on Adaptation to Space," sex was defined as "the classification of male or female according to an individual's genetics." Gender was defined as "a person's self-representation as male or female based upon social interactions." So far, when NASA has sent individuals into space, it has identified their sex, made no reference to their gender self-representation, and steered clear of the related matter of sexual orientation—that is, which sex(es) an individual finds attractive. **—ND**

ILLUSTRATION: MALIKA FAVRE

MEN TEND TO EXCEL IN SHORTER-TERM, GOAL-ORIENTED SITUATIONS, WHILE WOMEN ARE BETTER IN LONGER-TERM, HABITATION-TYPE CIRCUMSTANCES.

which direction is up or down. Fluids shift, immune responses decline, a handful of genes substantially change their expression patterns, and, problematically, eyesight enigmatically deteriorates.

Since the earliest days of the Mercury program, NASA has been gleaning medical data from its astronauts by studying their physiological responses to spaceflight. In 2014 the space agency released a large report compiled from decades of data. "It's only been recently that we've had multiple women flying on missions," so the findings on sex-based disparities are preliminary, says Virginia Wotring of the Center for Space Medicine at Baylor College of Medicine. Men seem to be less affected by space motion sickness but quicker to experience diminished hearing. Women appear to have a higher incidence of urinary tract infections (an issue not unique to spaceflight, as any woman will tell you).

More significantly, men tend to have problems with deteriorating vision, which women don't experience as often or as severely. NASA astronaut Scott Kelly—who has spent a cumulative 520 days in space and has the eye problems to prove it—half-jokingly wrote in his autobiography that if scientists can't figure out what's causing those eye issues, "we just might have to send an all-women crew to Mars."

NOT A BAD IDEA. But there are considerations beyond the physical. While cooped up in a cramped spaceship for months or years, how well would an all-female crew get along? It turns out (surprise!) that scientists know little about how all-female crews might fare in an intense and monotonous space environment.

In the few studies that have been done to identify factors in long-duration missions' success or failure, scientists observed teams that experienced stressful Earth analogs such as desert survival treks, polar expeditions, and Antarctic winter-overs. They found that men tend to excel in shorter-term, goal-oriented situations, while women are better in longer-term, habitation-type circumstances.

"People in habitation situations have to be more interpersonally sensitive. You have to notice, be more communicative," says Sheryl Bishop, a University of Texas Medical Branch psychologist who specializes in studying group behavior. "Women are acculturated to have a lot of those skills to begin with." That doesn't mean men can't get along well on long-duration space missions; it just means that the traits crucial for success on those missions are more typically associated with women.

FINALLY, THERE'S THE ISSUE that may be the least immediate and most provocative: populating a faraway planet. You could send a crew of three women and three men, and tell them to go have fun and make more humans. But again, looking at costs: Why send men when you can send just their contributions to the next generation, collected and cryopreserved in tiny vials? Sending an all-female crew and a sperm bank lets a space program economize while also increasing the genetic diversity of the parental pool.

Let's review. In terms of value per pound, tolerance of physical effects, psychosocial skills, and ability to bear astro-babies, women seem well suited to lengthy space voyages. Does this mean, conversely, that there's no reason to send men on these missions?

Not quite. Data on group dynamics suggest that in team endeavors, mixed-gender teams are the most successful overall. We can specify why females would do well on long-term space adventures—but we can't say flatly that an all-female crew would do the best. (However, it would almost certainly be better than a crew of hefty, squinting, inflexible, barren guys.)

For 192 years, all U.S. Supreme Court justices were men. Asked when there'd be enough women on the court, Justice Ruth Bader Ginsburg shocked some people with her answer: "When there are nine." There's never been an all-female crew of astronauts in flight—but decades of all-male crews. When will there be enough women in the spacecraft? When everyone who's qualified has an equal shot at a seat. ▯

Nadia Drake is a *National Geographic* contributing writer with a particular fondness for moons, spiders, and jungle cats.

PHOTO: NASA

Firsts for females in space

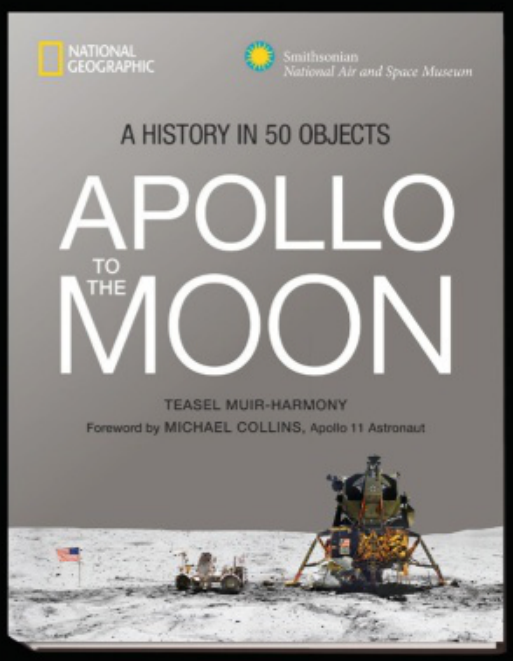
JUNE 16-19, 1963
Valentina Tereshkova
The Soviet cosmonaut was the first woman in space. She spent about 70 hours in the spacecraft Vostok 6, completing 48 Earth orbits.

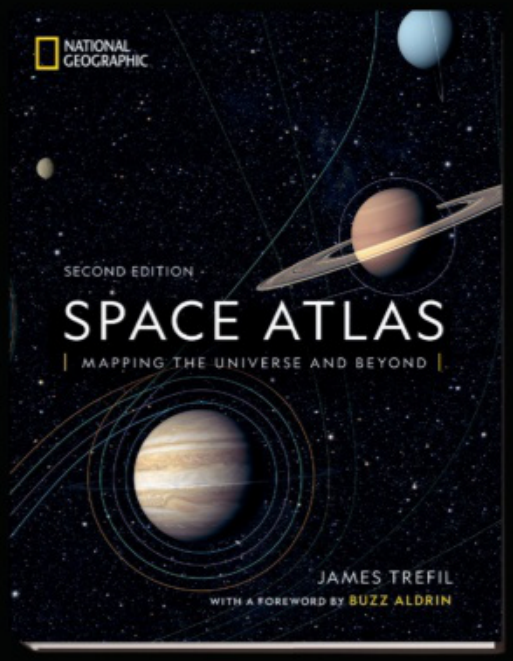
JUNE 18-24, 1983
Sally Ride
The NASA astronaut became the first U.S. woman in space, as well as the third woman there, when she flew the *Challenger* space shuttle mission.

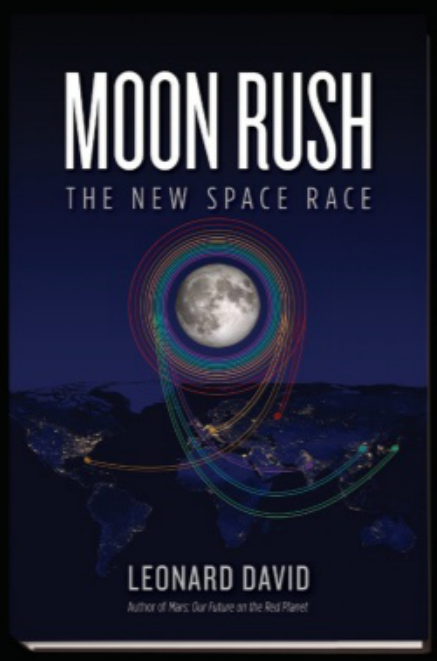
JULY 25, 1984
Svetlana Savitskaya
The Soviet cosmonaut was the first woman to take a space walk, performing tasks outside the Salyut 7 space station for about 3.5 hours.

OCTOBER 10, 2008
Peggy Whitson
The NASA astronaut became the first female International Space Station commander on a 2008 expedition; she held command there again in 2017.

NAVIGATE THE UNIVERSE







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STRAW POLL: WHICH ONES ARE ECO-FRIENDLY TO USE?

PHOTOGRAPH BY **REBECCA HALE**

MORE THAN 100 MILLION single-use straws—most of them plastic—are used in the United States each day. They end up in waterways, harm sea animals, and break down into microplastics that are becoming ubiquitous on Earth. Numerous places have passed plastic-straw bans as a way to start addressing the global plastic waste problem. Disability advocates, however, have pushed back on bans: They say straws are a necessary, everyday tool for many people, and nonplastic versions may not be suitable substitutes. –SARAH GIBBENS

Straw materials: Assets and disadvantages

1. METAL

Made of stainless steel, aluminum, or even titanium, metal straws have become a popular alternative. They draw some criticism—for having a metallic taste, conducting heat from a hot drink, and clanking against the teeth—but they're durable to transport and reuse.

2. PAPER

Paper drinking straws, which date from the late 1800s, often absorb liquid over time, become mushy, and can leave a taste or fibers in drinks. They're the most popular throwaway option in places with plastic-straw bans.

3. SILICONE

This material provides a popular soft alternative to metal reusable straws. One company has developed a silicone straw with an extra environmental twist: When burned, it turns into biologically inert ash.

4. GLASS

Though glass straws may be more breakable and thus less portable than reusable straws of other materials, they hold up well to washing and reuse. Some makers add an artistic flair to the straws with colors and blown-glass designs and ornaments.

5. HARD PLASTIC

Reusable straws made from rigid plastic are portable, easy to clean, and reasonably durable. Think of your typical reusable plastic water bottle shrunken to straw size.

6. BAMBOO

This natural material can be sustainably produced and is a plant-based alternative to fabricated straws. Bamboo straws are reusable but can be hard to clean completely and may absorb flavors. When it's time to dispose of them, they're easily compostable.

7. BENDABLE STRAWS

When bendable straws were first made in the 1940s, they were a boon in health-care settings to help patients drink without sitting up. Plastic bendable straws have become the safe, low-cost default in such settings—but the hunt is on for greener alternatives.

Learn more about plastic waste and take the pledge to reduce it at ***natgeo.com/plasticpledge.***

GENIUS

ELIZABETH MYNATT

BY **JEREMY BERLIN** PHOTOGRAPH BY **DAN WINTERS**

Elizabeth Mynatt directs Georgia Tech's Institute for People and Technology.

She wants people to live longer, healthier lives—through computing.

Like other computer scientists, Elizabeth Mynatt uses cutting-edge tech. What sets her apart is her holistic, humanistic approach. "I always say I'm designing for both sides of the equation," she says. "And the people side is always the hardest."

Mynatt's work on health informatics and assistive technology has allowed blind programmers to take advantage of graphical computer applications, helped pediatric epilepsy patients and their caregivers use mobile sensing apps, and supported older adults who want to age in place. "The burdens of chronic disease and aging populations are increasingly falling to patients and families," she says. "And because they've grown up with technology, they're looking to tech to have a role—and to make things better."

One of Mynatt's recent artificial intelligence projects is a preconfigured tablet computer that gives breast-cancer patients in rural Georgia personalized advice on everything from surgery and chemotherapy to dealing with anxiety and connecting to social services. Her latest effort, in partnership with Emory University, helps aging patients diagnosed with mild cognitive impairment, the stage that can lead to dementia.

"In my work, I always ask, What are the fundamental human needs here? And how does human behavior come into this situation?" says Mynatt. "Only when you combine the answers to both those questions do you end up creating designs that powerfully improve ways that people can take care of their own health and their families." ▯

'I'M DESIGNING FOR BOTH SIDES OF THE EQUATION. AND THE PEOPLE SIDE IS ALWAYS THE HARDEST.'

WHAT'S SO FUNNY?

IT CAN BE HARD TO GUESS what might make a stranger laugh. Now researchers at the University of Alberta, in Canada, have developed a formula. After reading a study in which participants rated the humorousness of some 5,000 English words, psychologists Chris Westbury and Geoff Hollis wanted to break down what makes a word intrinsically comical. They expanded the list to almost 45,000 words, then generated a complex statistical model to score the funny factors and analyze the humor of each one.

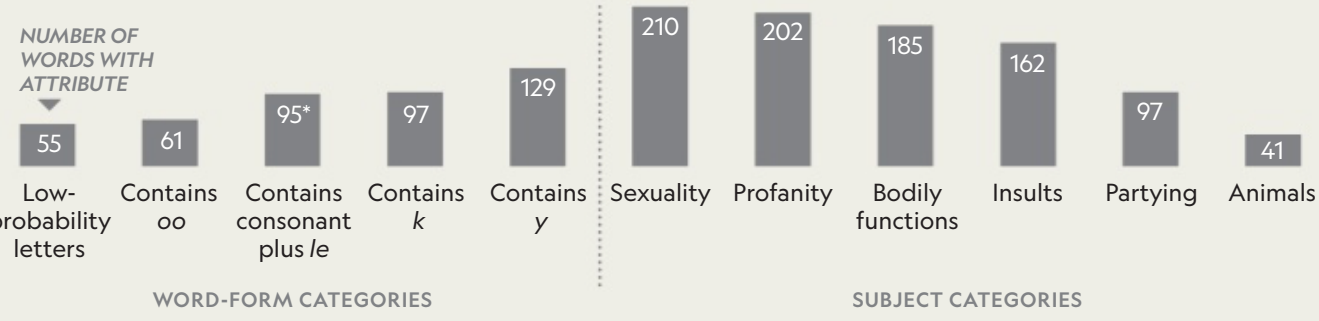
BY **RYAN MORRIS** AND **ALEXANDER STEGMAIER**

ANATOMY OF A SIDESPLITTER

Westbury and Hollis discovered there are two main predictors of what makes a word funny: how it looks and sounds, and the meaning behind it. "Pizzazz" is comical for its unusual combination of letters, but typically it's the definition of a word that tickles us the most. Try not to smirk when you say "booger."

RECIPE FOR LAUGHTER

A closer look at the 500 words that Westbury and Hollis ranked as funniest reveals common ingredients. "Puking," for example, has a funny-word form—the *oo* sound and the letter *k*—as well as associations with profanity, bodily function, and partying, three of the six funny-word categories in the study.



*WORDS LABELED AS CONTAINING A CONSONANT PLUS *LE* INCLUDE VARIATIONS SUCH AS *-LING, -LY,* AND OTHER WORDS WITH SIMILAR MEANINGS.
SOURCE: CHRIS WESTBURY AND GEOFF HOLLIS, UNIVERSITY OF ALBERTA

DISPATCHES
FROM THE FRONT LINES
OF SCIENCE
AND INNOVATION

Flight of the Dandelion

By studying dandelion seeds as they drift in the air, researchers uncovered a new form of flight. A hovering vortex created by air flowing up through the seed's pappus, the tuft at its top, helps the seed float. The find could explain how other life-forms move and how filter feeders eat. –CZ

NEUROSCIENCE

To Sleep, Perchance to Heal

A report in the journal *Nature Communications* adds to the list of sleep's benefits. In imaging studies of the brains of zebrafish, scientists saw that cells' DNA repair systems could not fix a day's accumulated damage during waking periods—but that they were far more efficient during periods of sleep. Researchers say this find may help illuminate the connections between sleep habits, brain health, and aging.

–CATHERINE ZUCKERMAN

ANIMALS

MYTHICAL CREATURE FOUND IN ANCIENT WOOD

PRAYING MANTIS IS A SVELTE 'UNICORN'

Researchers exploring Brazil's Atlantic Forest discovered some five to seven new species of praying mantises. Among the newfound creatures are unicorn mantises, which have mysterious, hornlike structures on their heads, as seen above on a member of the genus *Zoolea*.

It's unclear exactly what purpose the protuberances serve. Perhaps they're "meant to break up the silhouette of the animals," says team leader Leonardo Lanna, whose Projeto Mantis expedition was funded by the National Geographic Society. Predators may then mistake them for something inedible, such as a leaf bud. Unlike their magical namesake, the praying mantises of the Atlantic Forest are experts in the art of blending in. **–DOUGLAS MAIN**

PHOTOS: LEONARDO LANNA (ABOVE); MAGNUS WENNMAN (LEFT)

IN THIS SECTION
Storied Boots
A Salty Swim
Argonaut Sacrifice
Firefly Forest

ILLUMINATING THE MYSTERIES—AND WONDERS—ALL AROUND US EVERY DAY
NATIONAL GEOGRAPHIC | VOL. 236 NO. 1

NEW PLACES TO GO

A TOILET IS LIKE A "SUPER VACCINE," says Doulaye Kone of the Bill & Melinda Gates Foundation. "It kills disease where it is produced." Traditional sanitation systems are costly to build and maintain, so the foundation's Reinvented Toilet initiative is helping to develop alternatives such as the toilets seen here. Safe and inexpensive to operate, these commodes can function without running water and, in some cases, electricity. They're also sustainable, eliminating pathogens while recovering nutrients and energy.

NANO MEMBRANE TOILET | HTCLEAN TOILET SYSTEM

Untreated water
Treated water
Solids

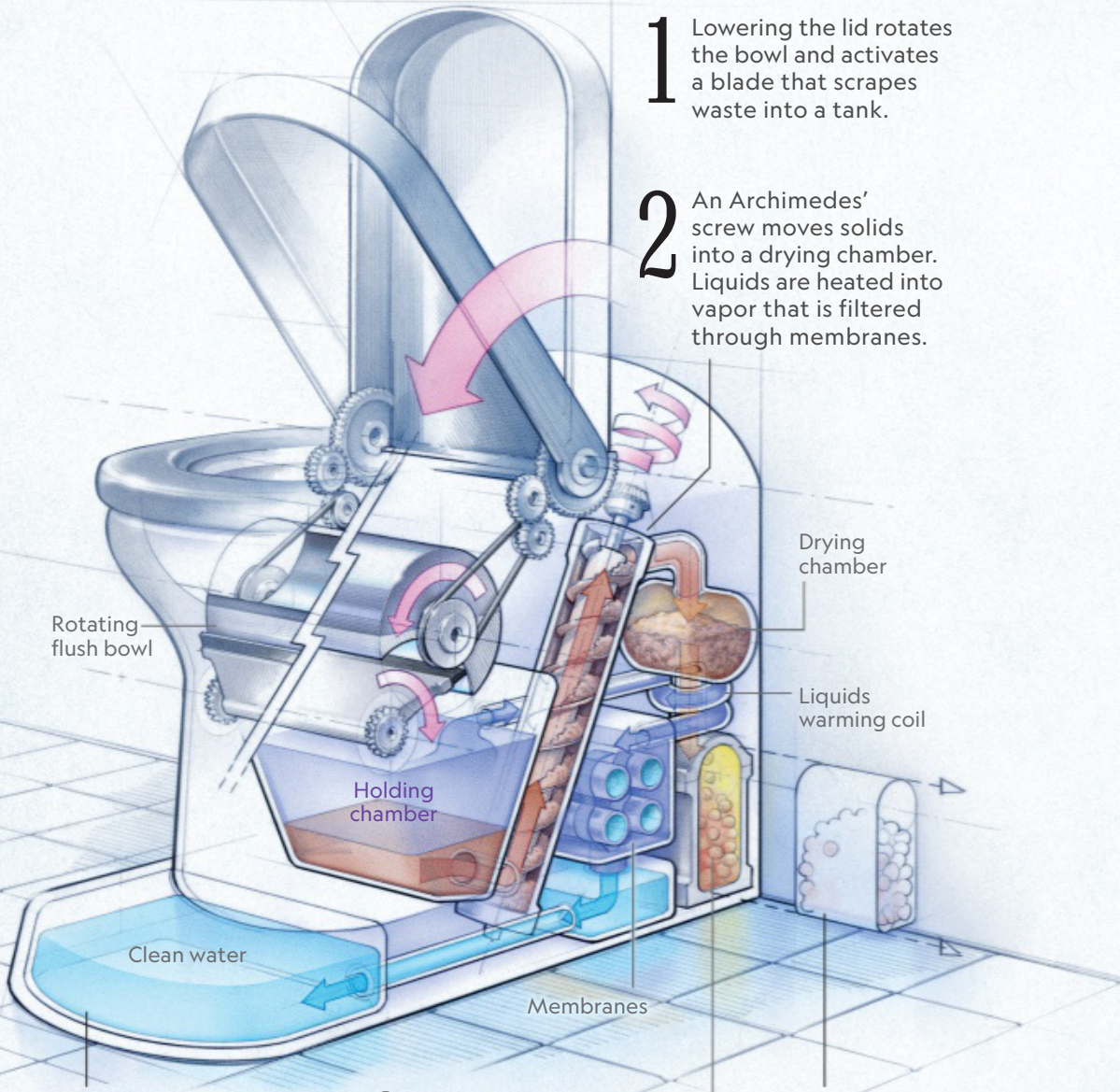
MECHANICAL DRY BIO-COMBUSTION

The Nano Membrane Toilet is a portable, self-contained unit that doesn't require external power. Waste is mechanically separated. A combustor dries and burns the solids, while liquids are heated and purified. The resulting sanitized ash and water can then be removed for safe disposal.

10 USERS PER DAY

10 YEARS' LIFE SPAN

THE PROCESS TAKES LESS THAN 24 HOURS TO COMPLETE.



1 Lowering the lid rotates the bowl and activates a blade that scrapes waste into a tank.

2 An Archimedes' screw moves solids into a drying chamber. Liquids are heated into vapor that is filtered through membranes.

The purified vapor condenses into water, which flows into a tank that also serves as a footrest.

3 Dried solids fall into the combustion chamber, where a self-sustaining burning cycle turns them to ash.

The ash—as much as 100 grams a day for 10 users—is emptied daily.

A GLOBAL PROBLEM

More than half the world's people lack safe sanitation. Almost a billion defecate outdoors. Some 361,000 children under age five die each year from sanitation-related diseases. It's an urgent issue in cities, where two-thirds of us may live by 2050.

DECODER | BY **MANUEL CANALES**

HIGH PRESSURE AND HEAT

HTClean's vacuum flush uses water reclaimed from the toilet's high-temperature and pressure-separation process. The result is purified water and disposable solid-waste cakes. The sewer-free commode currently relies on electricity, but scientists are working to make it completely off-grid.

10	20	
USERS PER DAY	YEARS' LIFE SPAN	ELECTRICITY REQUIRED

THE PROCESS TAKES ABOUT 3-4 HOURS TO COMPLETE.

2 The waste is preheated and moved to a reactor where pressure and more heat turn it into liquid and carbonic material.

Vent

Output tank for solids

Normal use yields about 30 10-gram waste cakes a day.

Clean-water tank

Reactor chamber

Multistage filters purify the liquid into water that is used to flush the toilet.

3 A mechanical press squeezes liquid out of the material, leaving cakes of waste that can be safely discarded and water that is then sent through filters.

Collection tank

Output tanks for liquid

1 A low-water flush is activated by touch screen. Vacuum suction moves the waste and water into a collection tank.

Excess liquid is moved to a tank for disposal or another use.

PATRICIA HEALY. ART: BRUCE MORSER. SOURCES: BILL & MELINDA GATES FOUNDATION; ALISON PARKER, CRANFIELD UNIVERSITY; CHRISTIAN SEILER, HELBLING; WHO/UNICEF JMP; UNESCO WWAP

A FROSTBITTEN EVEREST DESCENT

THE FIRST SUCCESSFUL U.S. EFFORT TO REACH THE SUMMIT OF EVEREST TOOK A TOLL ON THE OWNER OF THESE BOOTS.

PHOTOGRAPH BY **REBECCA HALE**

BARRY BISHOP RETURNED from a historic Mount Everest expedition with his reindeer-hide boots, Vibram-soled hiking boots (below), knee-high overboots with crampons—and no toes.

A polar researcher turned National Geographic photographer, Bishop was on the first U.S. expedition to summit Everest. At 3:30 p.m. on May 22, 1963, he and his climbing partner reached the top, dropped to the ground, and wept. On the descent they couldn't find their camp. Bishop stamped his feet to warm them but soon felt sharp pain, then numbness. "Knowing it is hopeless, I abandon the effort," he later wrote.

After Bishop spent a night without shelter, his toes turned "dead white, hard, and icy to the touch." Crippled by frostbite, he was carried partway down the mountain by Nepalese Sherpas and evacuated by helicopter to a hospital in Kathmandu. An American doctor flew in to administer an experimental drug to revive the damaged tissue in his feet, but it failed.

Along with all of his toes, Bishop lost the tips of two fingers. Still, he continued to climb—and his son, Brent, conquered Everest in 1994, making it a father-and-son feat. "There are no true victors," Barry Bishop wrote of the mountain. "Only survivors." **—NINA STROCHLIC**

Barry Bishop made it to the top of Everest but was crippled by frostbite on the descent. He wore these hiking boots—each weighing nearly four pounds—as Sherpas carried him partway down.

HOW DOES THIS OCEANIC ODD COUPLE MANAGE TO HAVE SEX?

PHOTOGRAPH BY **JULIAN FINN**

LEST YOU DOUBT the awesome power of the drive to procreate, consider what Mr. and Mrs. Argonaut *(Argonauta argo)* must go through to send baby argonauts out into the world.

This octopus species lives in open water in Earth's tropical and subtropical seas. It's not the easiest place to find a mate, especially since the male is tiny—less than three-quarters of an inch long—while the female can be up to 30 times his size. She has two specialized dorsal arms that secrete a chalky substance, forming a pleated shell in which she can hide, float, and brood eggs. The male is sans shell, but he too has a specialized arm: a tentacle-like, detachable copulatory organ called a hectocotylus.

After attaching to the female, the male releases his hectocotylus, which worms its way into the female's mantle cavity. She may stockpile these disembodied sperm arms from several mates and use them to fertilize her eggs over time. She'll lay strings of eggs tethered to her shell (also called an egg case) where she can tend them as they develop. Scientists know this because they've been able to observe argonaut mothers live—but not fathers.

After donating his paternal part, no male has been seen alive growing a new one; only dead specimens have been found. As his last act, the small but mighty paterfamilias gives an arm and a life to the cause of reproduction. **—PATRICIA EDMONDS AND EVA VAN DEN BERG**

Greater argonaut *(Argonauta argo)*

1. NAME GAME

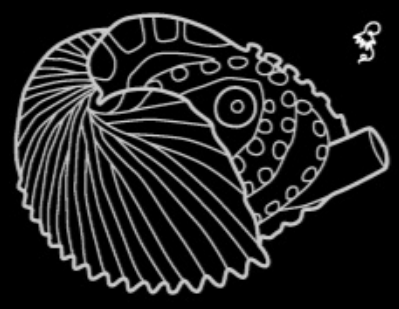
This species of octopus is also known as the paper nautilus (the shell it builds to hold its eggs is made of paper-thin calcium carbonate). The Chinese name for the species translates to "white seahorse's nest."

2. ARGONAUT MYTH

In 300 B.C. Aristotle described his vision of a female argonaut using her shell as a boat and her tentacles as sails and oars. In 2010 octopus experts Julian Finn and Mark Norman documented what actually occurs: The argonaut moves by expelling jets of water, surfaces enough to trap air in her shell, then is buoyed at an optimal water level by the air bubble.

3. COMMON, ELUSIVE

Though rarely seen by humans, *A. argo* is widespread in Earth's more tropical oceans. It's preyed upon by tuna, dolphins, and billfishes but still described as of least concern on the IUCN Red List of Threatened Species.



J. FINN, MUSEUMS VICTORIA, AUSTRALIA; TAYLOR MAGGIACOMO, NGM STAFF (ILLUSTRATION)

BY THE NUMBERS

2
HOURS FROM JERUSALEM, BY CAR

34%
SALT CONCENTRATION

1,424
FEET BELOW SEA LEVEL

The Dead Sea is the lowest point on the surface of the Earth.

A SALTY

Visiting an island-like salt formation in the Dead

‘THE ONLY WAY TO GET THERE IS BY SWIMMING. IT’S REALLY PAINFUL BECAUSE THE WATER IS SO SALTY.’

—Ricardo Braz

ISLAND IN THE SEA

Sea meant a swim in one of the world’s briniest bodies of water.

BY **NINA STROCHLIC** PHOTOGRAPH BY **GUY DAVIES**

A FEW YEARS AGO Ricardo Braz was scrolling through Instagram when he spotted a picture of a tiny island made of salt in the Dead Sea. He added it to his bucket list. In December the 24-year-old freelance photographer traveled to Israel, borrowed a drone, and set off in search of the island.

T MINUS ONE DAY

HEADING TO THE SEA

Braz spent a week exploring the desert of Jordan, the ruins of Petra, and the Red Sea during a photography workshop. Then he and friends Vilma Öhrman and Guy Davies rented a car and headed to the border with Israel. The three waited hours for a military drill to finish before they could cross. From there, a shuttle dropped them in Jerusalem, and the next morning they headed off in another rental car for the Dead Sea and a small resort area called Ein Bokek.

T MINUS ZERO DAYS

ESSENTIAL PACKING LIST

The Dead Sea is nearly 10 times as salty as average ocean water. Swimming in the sea and exploring the other attractions around it require a unique set of supplies—including some that Braz wished he had thought to bring.

- Swimming goggles
- Extra water
- A towel
- A drone or contact for drone rental
- Compact down jacket for cold desert nights
- A wide-angle lens
- Hiking boots

T MINUS ZERO HOURS

READY FOR LAUNCH

“We tried to take pictures of the island from a distance, but it wasn’t even worth it,” says Braz. After a test flight with the drone, the group drew straws to decide who would stay to operate it (Davies) while the others swam to the island. During the 15-minute swim, salt water stung the eyes and dried the mouths of Braz and Öhrman. Neither had brought goggles or a bottle of water. On the island, they basked in the sun while the drone flew overhead, snapping photos.

Flashes in the Dark

A PHOTOGRAPHER SHIFTS HER GAZE FROM THE ONGOING INSTABILITY AND VIOLENCE IN MEXICO TO THE FLEETING BEAUTY OF ONE OF THE COUNTRY'S NATURAL WONDERS.

BY **KIRSTEN LUCE**

WHEN AN EDITOR CALLED TO ASK if I could photograph a story about fireflies in Mexico, I didn't check my schedule before I said yes. I'd seen these insects light up the forests in Tlaxcala once before, and I jumped at the chance to go back.

While studying at the University of Colima, I began exploring Mexico, crossing the country several times by bus. I've spent time in 28 of its 31 states, and the variety of landscapes—Michoacán's beaches, Colima's volcano, San Luis Potosí's plateau—captivates me in a way that no other country has.

Now I work as a photojournalist in Mexico and along the border, documenting desperate situations that rarely seem to improve for everyday Mexicans. I'm lucky enough to be able to leave when I need to; my Mexican colleagues face censorship and threats to their lives.

Though necessary and important, news stories don't reflect the Mexico that I fell for and that is home to so many people I love. An assignment focused on the country's natural beauty was a welcome reprieve.

I had three nights to capture the magical scene in the forest. Tripod in hand, I hiked with my colleagues into the misty forest at dusk. I set up, and we waited, our banter dissipating as the daylight waned and tiny specks of light emerged.

According to our guides, visitors are usually not allowed to photograph the fireflies because the presence of artificial light from electronics can

affect their habits. As I started shooting, I adjusted my exposures constantly to account for the fading light. In order to get the composition that I wanted, I placed my tripod on a steep, rocky path and had to steady it during the long exposures. Normally this wouldn't be a big deal, but the fireflies were very interested in the camera and, by extension, in me. I stood completely still while they crawled all over me—my arms, my hair, my face—and tickled my nose and cheeks. From what I observed, peak firefly presence happens for only about 20 minutes each night, so I had time for just a few tries.

On the last night everything came together. The weather cooperated. I had improved my method for focusing and composing in the dark with quick flashes from a powerful flashlight—and I'd grown accustomed to insects on my face.

I was rewarded with the image you see here. Each speck of light is one of several bursts that a firefly makes as it travels within a 30-second exposure. You can trace the insects' paths: Some make small loops, like those in the bottom center of the frame, while others move steadily in one direction or another.

The first time I visited the fireflies, I didn't have the pressure of trying to capture and convey this wondrous scene. I was just immersed and completely enchanted. That will always be my favorite experience with these luminous creatures. □

Kirsten Luce most recently photographed wildlife tourism for the June 2019 issue of the magazine.

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NATIONAL GEOGRAPHIC

PHOTO: KOSTADIN LUCHANSKY/OKAVANGO WILDERNESS PROJECT

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FEATURES

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'THE COLD, NUTRIENT-RICH WATERS FEED GIANT KELP FORESTS THAT HARBOR ONE OF THE MOST MAGNIFICENT MARINE ECOSYSTEMS ON THE PLANET.'

PHOTO: ENRIC SALA

COUNTDOWN TO A NEW ERA

IN SPACE

Astronaut Harrison Schmitt bounds toward the lunar rover during the Apollo 17 mission in December 1972, the last time humans set foot on the moon.

EDITOR'S NOTE: This image is part of a panorama that NASA created from 18 photos. To show how the lunar landscape looked to the astronauts, NASA removed lens flare from sunlight by blacking out the sky.

NASA/LUNAR AND PLANETARY INSTITUTE

Fifty years ago this month, astronauts walked on the moon for the first time. Apollo 11's success—just 66 years after the Wright brothers' first flight—showcased humankind's moxie and ingenuity. Now the moon is in our sights again, for a generation that will test where science meets profit.

00:0

:05	:04	:03
PIONEERS	GETTING THERE	WHERE WE WENT

ABOVE: Documenting the small steps of Apollo 11 astronauts, Buzz Aldrin took these photographs of his boot print.

T MINUS

0:06

:02	:01	:00
WHAT WE TOOK	IN POP CULTURE	WHAT'S NEXT

T MINUS

PIONEERS

LEFT: John Glenn wore this space suit, made with 27 zippers to ensure a tight fit, when he orbited Earth on February 20, 1962.

ANIMALS WERE OUR FIRST SPACE TRAVELERS, CLEARING THE WAY FOR ASTRONAUTS WHO BECAME FAMOUS—AND FOR LESSER KNOWN HEROES.

BY NADIA DRAKE

PHOTOGRAPHS BY DAN WINTERS

Yuri Gagarin, Alan Shepard, John Glenn, Neil Armstrong—the first wave of space travelers—were military-trained astronauts thought to have the "right stuff" for risky missions.

But early spaceflight wasn't the exclusive province of men—or even humans. Fruit flies, monkeys, mice, dogs, rabbits, and rats flew into space before humans.

More than three years before Gagarin became the first human in space with his April 1961 journey around Earth, the Soviets famously—or perhaps infamously—sent up a stray dog. Laika was the first animal to orbit Earth but died during her flight. The United States launched a chimpanzee named Ham into space. Happily, he survived, clearing the way for Shepard to became the first American in space in May 1961.

Despite discrimination, women were also pioneers. Some, such as mathematician Katherine Johnson—who hand-calculated the details of the trajectory of the flight that would make Glenn the first American to orbit the Earth in 1962—stayed behind the scenes. Valentina Tereshkova, an early cosmonaut, became the first woman in orbit in 1963. It wasn't until two decades later that Sally Ride flew on the space shuttle *Challenger* to become the first American woman to reach space.

TOP
Sputnik's launch on October 4, 1957, was covered on television, a relatively new and increasingly popular medium. The Soviet Union's surprise success at putting the first human-made object in space shocked the U.S. and triggered the superpower space race.
PHOTO ILLUSTRATION

ABOVE
Strelka shot into space in a Soviet craft on August 19, 1960, along with another dog, Belka; a rabbit; 40 mice; two rats; flies; and some plants and fungi. The menagerie made it back to Earth. The preserved dogs, hailed as heroes, are displayed in a Moscow museum.
MUSEUM OF COSMONAUTICS

RIGHT
The Apollo 11 crew, including the first astronauts to land on the moon, were carried into space on July 16, 1969, in this command module, the *Columbia*. The three men returned to Earth in the capsule, which splashed down southwest of Hawaii.
MUSEUM OF FLIGHT, SEATTLE

18+

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AVAXHOME-

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Cheap constant access to piping hot media
Protect your downloadings from Big brother
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18 years of seamless operation and our users' satisfaction

All languages
Brand new content
One site

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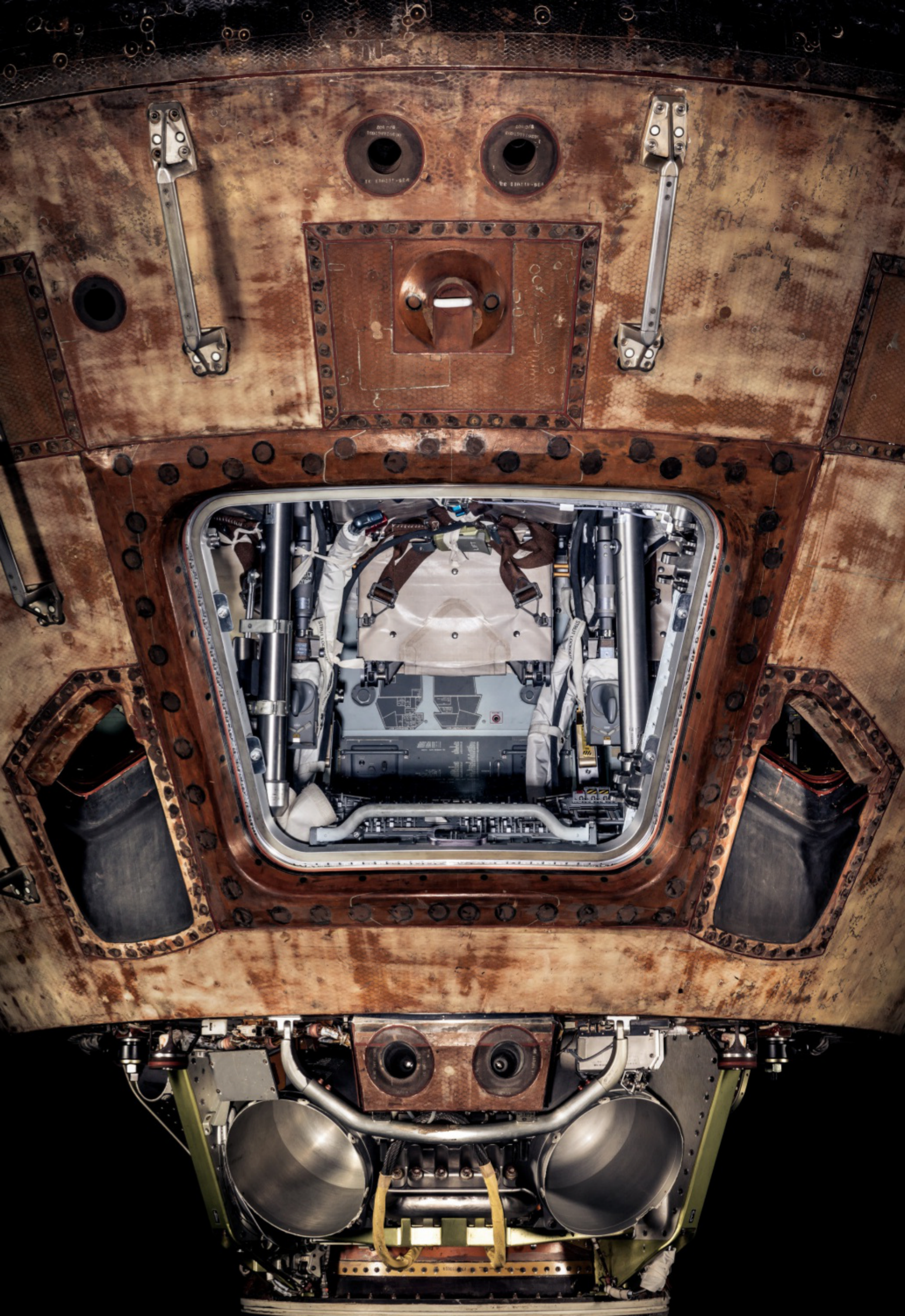


T MINUS

GETTING THERE

LEFT: Using old but still reliable technology, Russia launches a Soyuz rocket in March from its Baikonur Cosmodrome in Kazakhstan.

EARLY ROCKETEERS FIGURED THAT A MULTISTAGE LAUNCHER COULD PROPEL HUMANS TO THE MOON. THE SATURN V DID THAT—AND SET THE STAGE FOR THE FUTURE.

A bespectacled, bearded Russian recluse fond of science fiction, Konstantin Tsiolkovsky believed humanity's destiny lay among the stars. By the early 1900s, he had worked out the equation for humans to slip beyond Earth's gravitational pull. He also imagined how moon-bound rockets would work: using a mix of liquid propellants and igniting multiple stages.

Independently, Hermann Oberth and Robert Goddard reached similar conclusions. By 1926, Goddard, an American, had built and launched the first liquid-fueled rocket. About that time, Oberth, who lived in Germany, determined multiple stages are crucial for long journeys.

Four decades later, the trio's ideas roared to life in the enormous Saturn V rockets that thrust Apollo crews into space. Measuring 363 feet tall and fueled by liquid hydrogen, liquid oxygen, and kerosene, the Saturn V was the most powerful rocket ever built. Engineered by Wernher von Braun—a Nazi Germany rocket scientist who relocated much of his team to work for the U.S. after World War II—the Saturn V had three stages that fired in sequence. Rocketry is still governed by Tsiolkovsky's equation. But no rocket has yet eclipsed the Saturn V, which propelled humans closer to the stars than ever before.

FAR RIGHT

Five bell-shaped engines powered the initial stage of the Saturn V rocket, which shot most of the Apollo missions beyond Earth's orbit and eventually carried astronauts to the moon. Together the five engines generated as much energy as 85 Hoover dams.

NASA KENNEDY SPACE CENTER VISITOR COMPLEX

1950

1955

1960

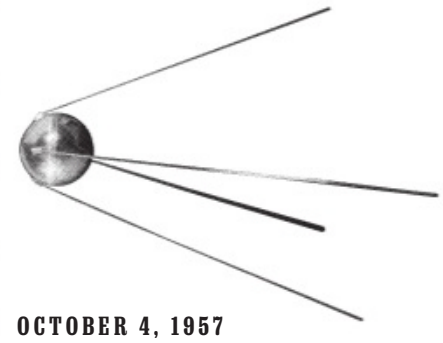
1965

1970

1975

RUSSIAN MILESTONES

JULY 22, 1951
Soviet Union begins suborbital flights with dogs as passengers.



OCTOBER 4, 1957
The Sputnik satellite is the first human-made object to orbit Earth.

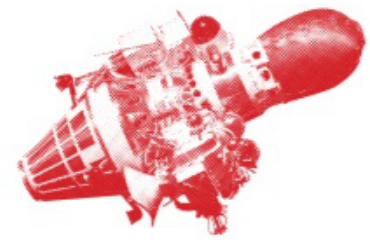
NOVEMBER 3, 1957
Sputnik 2 carries the first animal, a dog named Laika, into Earth orbit.

APRIL 12, 1961
Yuri Gagarin flies in Vostok 1, becoming the first human to reach space and orbit Earth.

JUNE 16, 1963
Vostok 6 is launched with Valentina Tereshkova, the first woman to reach space.

MARCH 18, 1965
Alexei Leonov conducts the first space walk.

FEBRUARY 3, 1966
Luna 9, an uncrewed spacecraft, achieves the first soft landing on the moon.



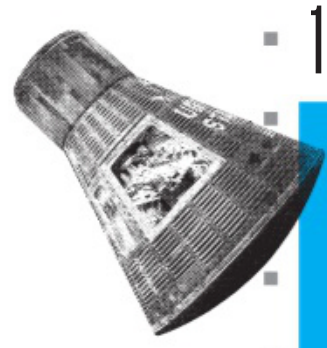
JULY 15, 1975
The Apollo-Soyuz Test Project becomes the first international partnership in space, between the U.S. and Soviet Union.

U.S. MILESTONES

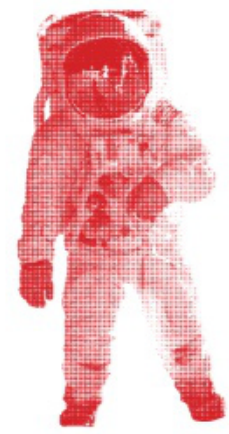
JANUARY 31, 1958
Explorer 1 becomes the first U.S. satellite to reach space.

MAY 5, 1961
Freedom 7 is launched with Alan Shepard, the first American to make a suborbital flight.

FEBRUARY 20, 1962
John Glenn becomes the first American to orbit Earth, piloting *Friendship 7*.



JULY 20, 1969
Apollo 11's Neil Armstrong and Buzz Aldrin are the first to walk on the moon.



PHOTOENGRAVINGS: SOVFOTO/UNIVERSAL IMAGES GROUP/SHUTTERSTOCK (SPUTNIK); OMIKRON/SCIENCE SOURCE/GETTY IMAGES (EXPLORER); GENE J. PUSKAR, AP/SHUTTERSTOCK (CAPSULE); SPUTNIK/SCIENCE PHOTO LIBRARY (LUNA 9); NASA (ALDRIN)

SOVIETS IN SPACE

The Soviets' Vostok ("East" in Russian) launched the first human, Yuri Gagarin, into one orbit around Earth.

The R7 was first used for space-flight to launch Sputnik. A third stage was added later; modified versions are still in use.

Spacecraft
VOSTOK 1
1961

Launch vehicle
R7
1957-present

Third stage

Second stage

First stage, four boosters

First stage

Launch vehicle
SPACE SHUTTLE
1981-2011

Orbiter
COLUMBIA
1981-2003

Parachutes

First stage

Solid rocket boosters could be refurbished after use if no damage was discovered.

Cargo bay

In-orbit fuel

First stage (reusable)

Landing legs open

FERNANDO G. BAPTISTA, KAYA BERNE, EVE CONANT, NGM STAFF; RONALD PANIAGUA
SOURCES: NASA; SMITHSONIAN'S NATIONAL AIR AND SPACE MUSEUM; SPACEX; *THE SOYUZ LAUNCH VEHICLE*, BY CHRISTIAN LARDIER AND STEFAN BARENSKY

Numbers are averages for specific vehicles above.

TOTAL WEIGHT

0.58 million lb

Fuel (%) 88% Spacecraft

PAYLOAD (crew and cargo) 11,000 lb (to low Earth orbit)

6.5 million lb

91%

250,000 lb

100,000 lb (to lunar orbit)

4.5 million lb

84%

63,500 lb

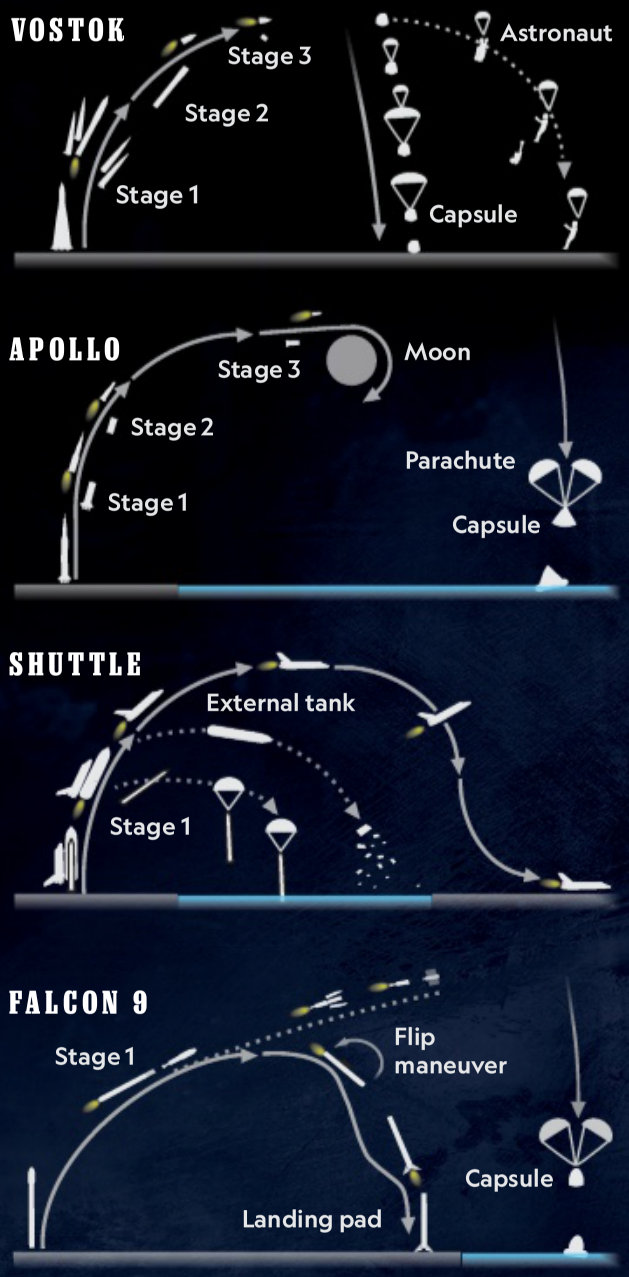
1.2 million lb
(proportions not available)

50,000 lb

LIFTING OFF

Rapid advancements in spaceflight occurred during the space race between the U.S. and the Soviet Union. Ballistic missiles for warfare evolved into rockets destined for exploration. Now commercial space companies are also building spacecraft and selling tickets for future tourist flights.

GETTING THERE AND BACK

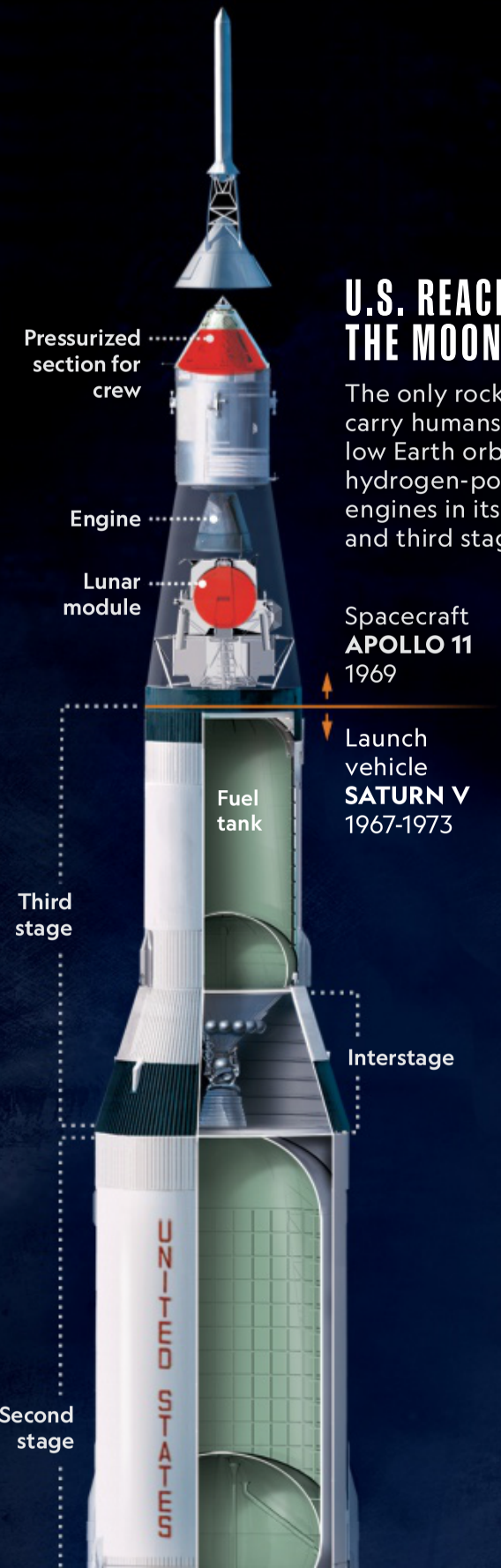


U.S. REACHES THE MOON

The only rocket to carry humans past low Earth orbit had hydrogen-powered engines in its second and third stages.

Spacecraft
APOLLO 11
1969

Launch vehicle
SATURN V
1967-1973

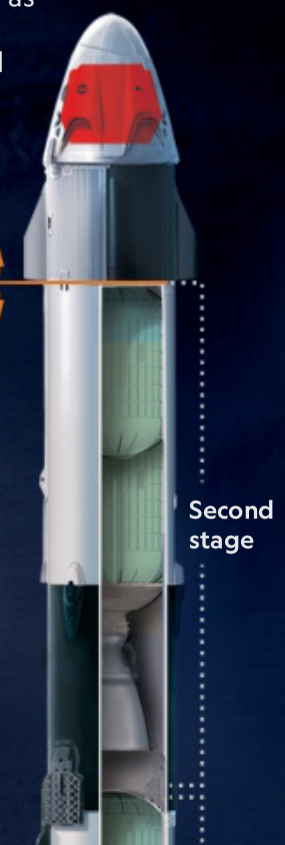


U.S. GOES COMMERCIAL

NASA has contracted with SpaceX to bring astronauts as well as cargo to the International Space Station.

Spacecraft
CREW DRAGON
2019

Launch vehicle
FALCON 9
2010-present



ROUND-TRIP TICKET

The world's first reusable spacecraft to carry humans into orbit could transport up to eight passengers.

A Soyuz spacecraft is towed to a launch-pad this past March at the Baikonur Cosmodrome. Developed by the Soviet Union in the 1960s, the durable design is still used by Russia's space program. Since the last space shuttle was retired in 2011, U.S. astronauts have hitched rides to the International Space Station on the Soyuz.

SUITING UP

Space suits—designed to provide oxygen and consistent atmospheric pressure—have evolved from pressure suits for pilots in high-altitude planes to ones that can keep astronauts alive in the near-vacuum conditions of space.

DESIGNED FOR SURVIVAL

Extravehicular Activity (EVA) Space Suits (E)

EVA suits allow for work outside spaceships. They protect against threats such as extreme temperatures, debris, and radiation.

Intravehicular Activity (IVA) Space Suits (I)

IVA suits are an emergency system for cabin contamination or decompression. Proper pressure keeps body fluids from boiling.

Intra/Extravehicular Activity (IEVA) Space Suits (IE)

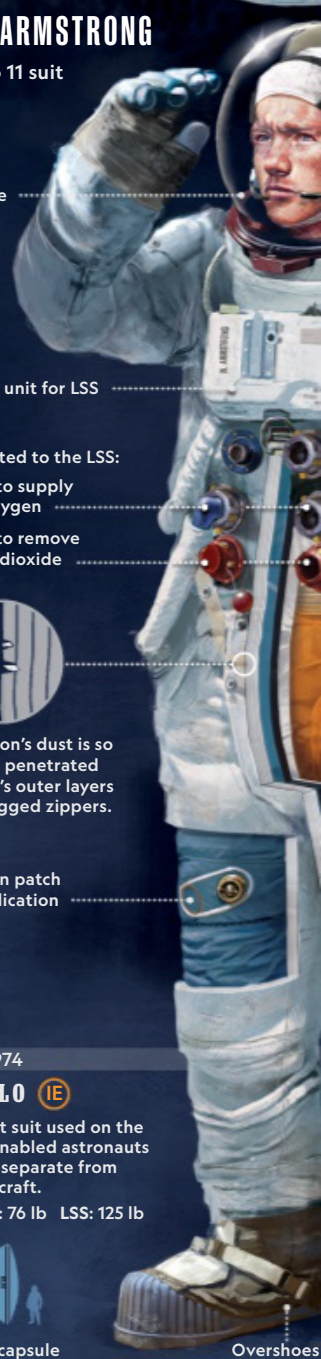
IVA suits accessorized to work outside, or IEVAs, eliminate the need for two separate suits and reduce cargo weight.

Suits shown pressurized

LUNAR EXTRAVEHICULAR VISOR ASSEMBLY
Two visors, one gold coated, shield user from the sun's rays and heat.

NEIL ARMSTRONG

Apollo 11 suit


Pressure helmet
Control unit for LSS
Connected to the LSS:
Valves to supply pure oxygen
Valves to remove carbon dioxide
The moon's dust is so sharp it penetrated the suit's outer layers and clogged zippers.
Injection patch for medication
Overshoes

1934-1935 (years worn)

WINNIE MAE (I)

Wiley Post designed the first pressure suit, made of cotton and rubber, and flew nearly 50,000 feet high in it.

Weight: not recorded

Lockheed Vega *Winnie Mae*

1959-1968

X-15 (I)

The suit was used on the first rocket-powered craft to hit the edge of space, 62 miles above sea level.

Weight: 25 lb

North American X-15

1961-1963

MERCURY (I)

This suit took on water in one landing; later Mercury suits had survival gear with flotation devices.

Weight: 22 lb

Mercury capsule

1965-1966

GEMINI (IE)

The first suit worn outside a vehicle was attached by an oxygen and tether line.

Weight: 34 lb **VCM:** 8 lb

Gemini capsule

1969-1974

APOLLO (IE)

The first suit used on the moon enabled astronauts to fully separate from a spacecraft.

Weight: 76 lb **LSS:** 125 lb

Apollo capsule

FERNANDO G. BAPTISTA, KAYA BERNE, EVE CONANT, NGM STAFF; JOSE DANIEL CABRERA PEÑA
SOURCES: KENNETH S. THOMAS; NASA; SMITHSONIAN'S NATIONAL AIR AND SPACE MUSEUM; RICHARD D. WATSON; AMY J. ROSS

UNDERGARMENTS

1. Liquid cooling garment prevents overheating
2. Urine-collection assembly

SPACE SUIT LAYERS

3. Comfort liner
4. Neoprene-coated nylon to retain pressure
5. Nylon restraint layer
6. Protective layers include thermal-regulating aluminized polymers and fire-resistant fabric

LIFE-SUPPORT SYSTEM (LSS)

7. Portable life-support system (up to six hours)
8. Emergency oxygen (30 minutes)

1983-today

SHUTTLE/ISS (E)

Suits, once customized, now have generic, swappable parts that fit men and women on the International Space Station.

Weight: 122 lb **LSS:** 187 lb

Shuttle

T MINUS

WHERE WE WENT

RIGHT: In 1966 and 1967 five orbiters photographed the moon, helping to identify sites where Apollo missions would land.

APOLLO MISSIONS FOCUSED ON THE MOON'S NEAR SIDE. NOW UNCREWED PROBES ARE REVEALING MORE ABOUT THE MOON AND BEYOND.

COUNTDOWN TO A NEW ERA IN SPACE | PAGE 62

NASA IMAGE COLLECTION/ALAMY STOCK PHOTO (TOP); NASA/U.S. GEOLOGICAL SURVEY/LUNAR AND PLANETARY INSTITUTE (2)

NEW PHASE OF EXPLORATION

National Geographic has always been at the forefront of lunar mapping. As the Apollo program closed in on its goal, cartographers relied on photos from 1966 and 1967 orbiter missions to create the February 1969 hand-painted map—considered the best reference at the time. Our newest version uses a mosaic of some 15,000 images and detailed height measurements from NASA's Lunar Reconnaissance Orbiter, which has surveyed the entire surface. The moon is peppered with probes and landers, the legacy of human efforts to explore it.

***A larger version of this map can be purchased at:* natgeo.com/spacemaps.**

Lunar missions

- Landing
- Crash or impact

Country or agency

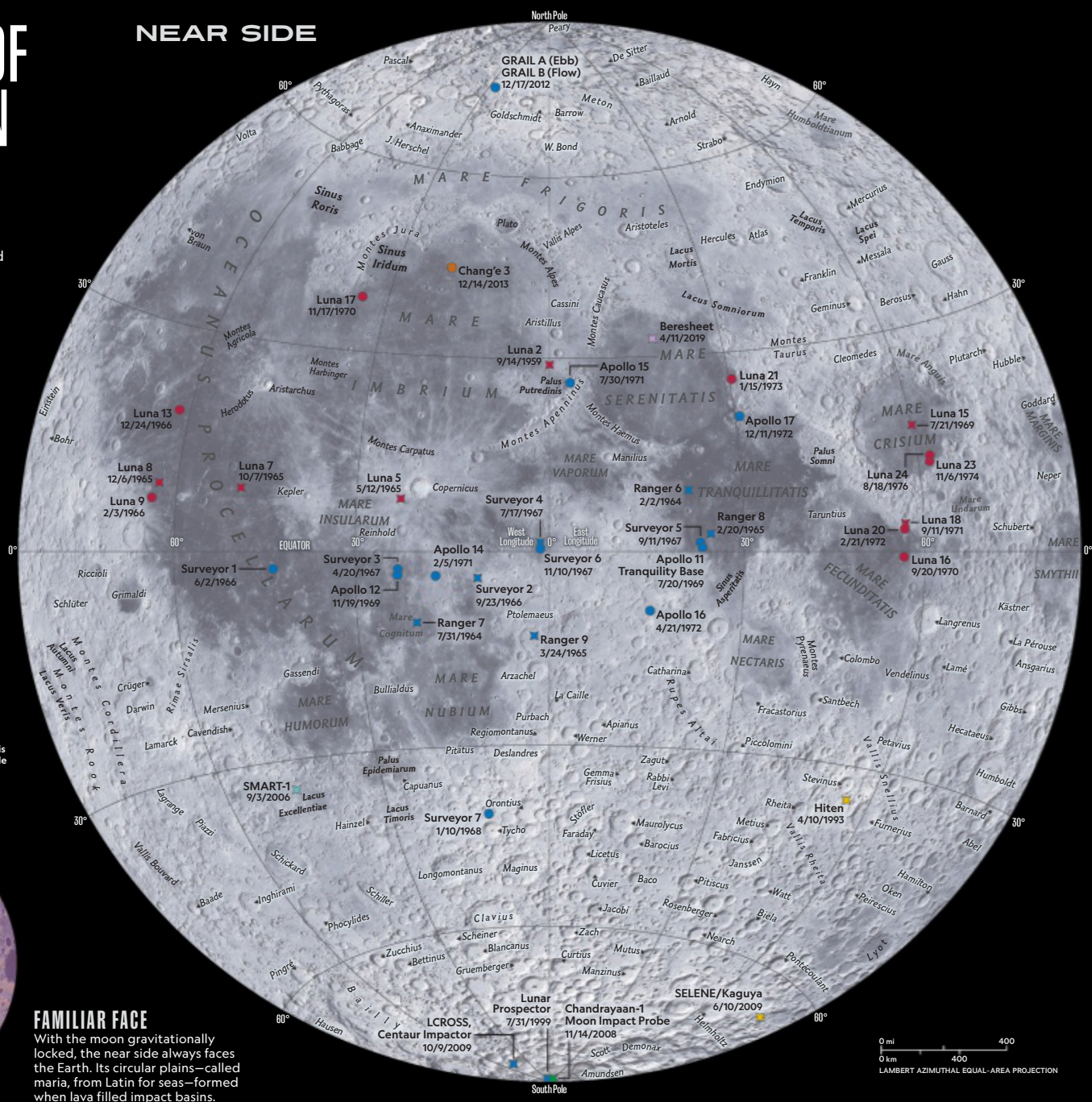
- United States (U.S.)
- Soviet Union (U.S.S.R.)/Russia
- China
- Japan
- European Space Agency (ESA)
- India
- Israel

Lunar topography (in feet)

30,000
15,000
0*
-15,000
-30,000

***As the moon has no sea level, zero is set where a sphere with a 1,079-mile radius would intersect the surface.**

NEAR SIDE



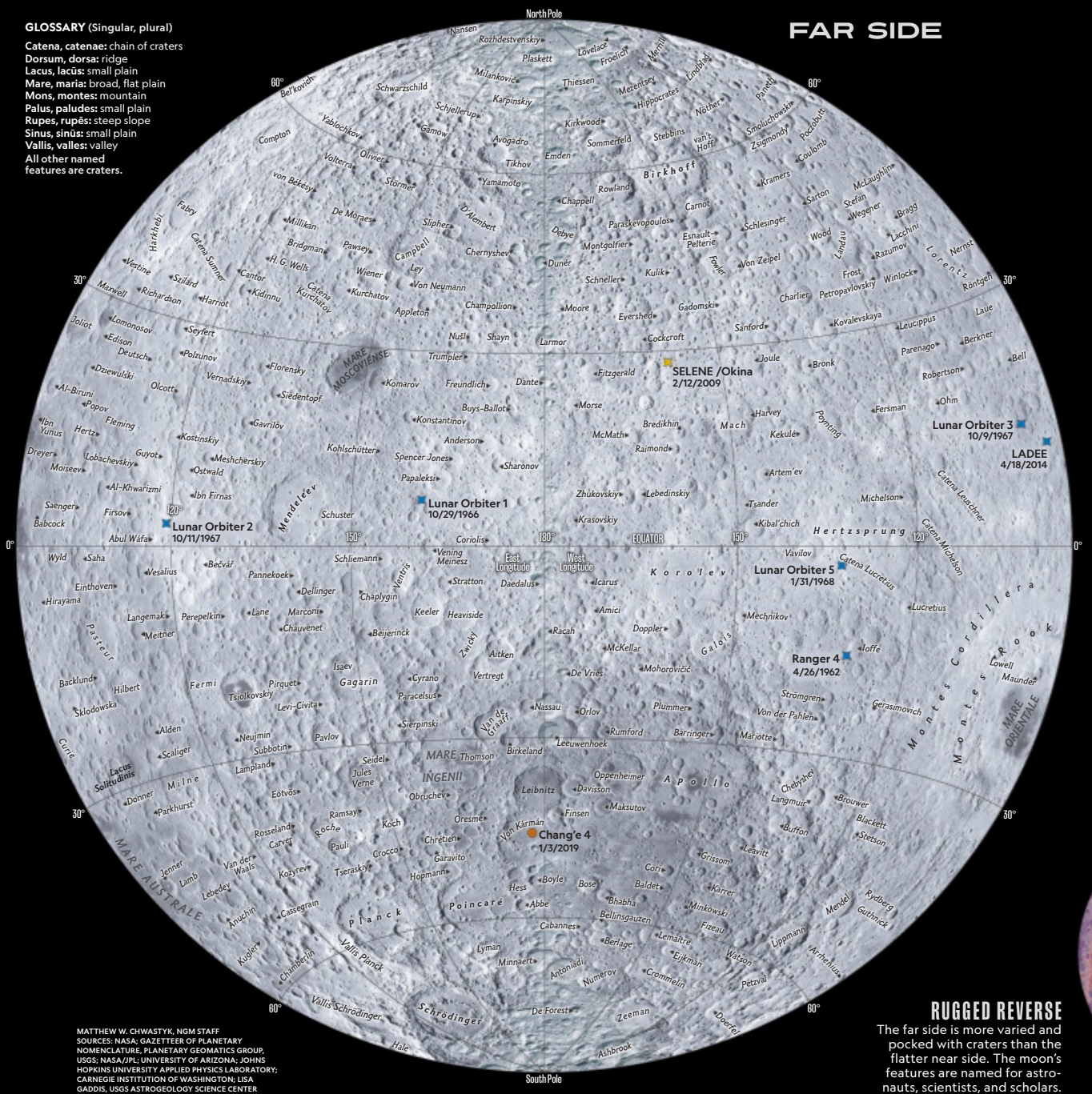
FAMILIAR FACE

With the moon gravitationally locked, the near side always faces the Earth. Its circular plains—called maria, from Latin for seas—formed when lava filled impact basins.

GLOSSARY (Singular, plural)

Catena, catenae: chain of craters
Dorsum, dorsa: ridge
Lacus, lacūs: small plain
Mare, maria: broad, flat plain
Mons, montes: mountain
Palus, paludes: small plain
Rupes, rupēs: steep slope
Sinus, sinūs: small plain
Vallis, valles: valley
All other named features are craters.

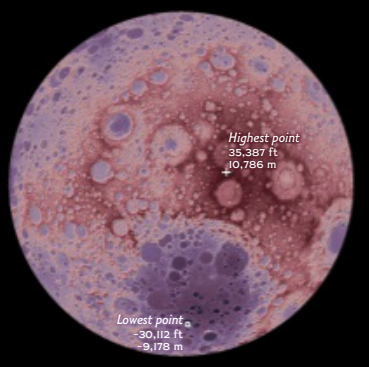
FAR SIDE



MATTHEW W. CHWASTYK, NGM STAFF
SOURCES: NASA; GAZETTEER OF PLANETARY NOMENCLATURE, PLANETARY GEOMATICS GROUP, USGS; NASA/JPL; UNIVERSITY OF ARIZONA; JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY; CARNEGIE INSTITUTION OF WASHINGTON; LISA GADDIS, USGS ASTROGEOLOGY SCIENCE CENTER

TO THE MOON OR BUST

The prize of the space race—landing humans on the moon and returning them home safely—fueled the rivalry between the U.S. and Soviet Union in the 1960s. Now robotic missions are determining whether the moon could be a stepping-stone for human ventures deeper into the solar system.



RUGGED REVERSE

The far side is more varied and pocked with craters than the flatter near side. The moon's features are named for astronauts, scientists, and scholars.

AFTER APOLLO

Nearly half a century has elapsed since humans last visite
But we never stopped exploring. We've inhabited research
(right) and sent robotic craft (below) to venture even far
selfies on Mars, plunge into Jupiter, and investigate our s

In the 1960s our moon was still very much a mystery. To learn the most from the Apollo visits, NASA selected landing sites in a variety of lunar terrains, including the dark, flat plains sculpted by vanished lava oceans and highlands formed by meteor impacts.

From 1969 to 1972, U.S. astronauts landed at six sites, each chosen for different scientific objectives. All of them were on the moon's mottled near side, where the terrain had been studied extensively by lunar orbiters and Mission Control could remain in direct contact with the astronauts.

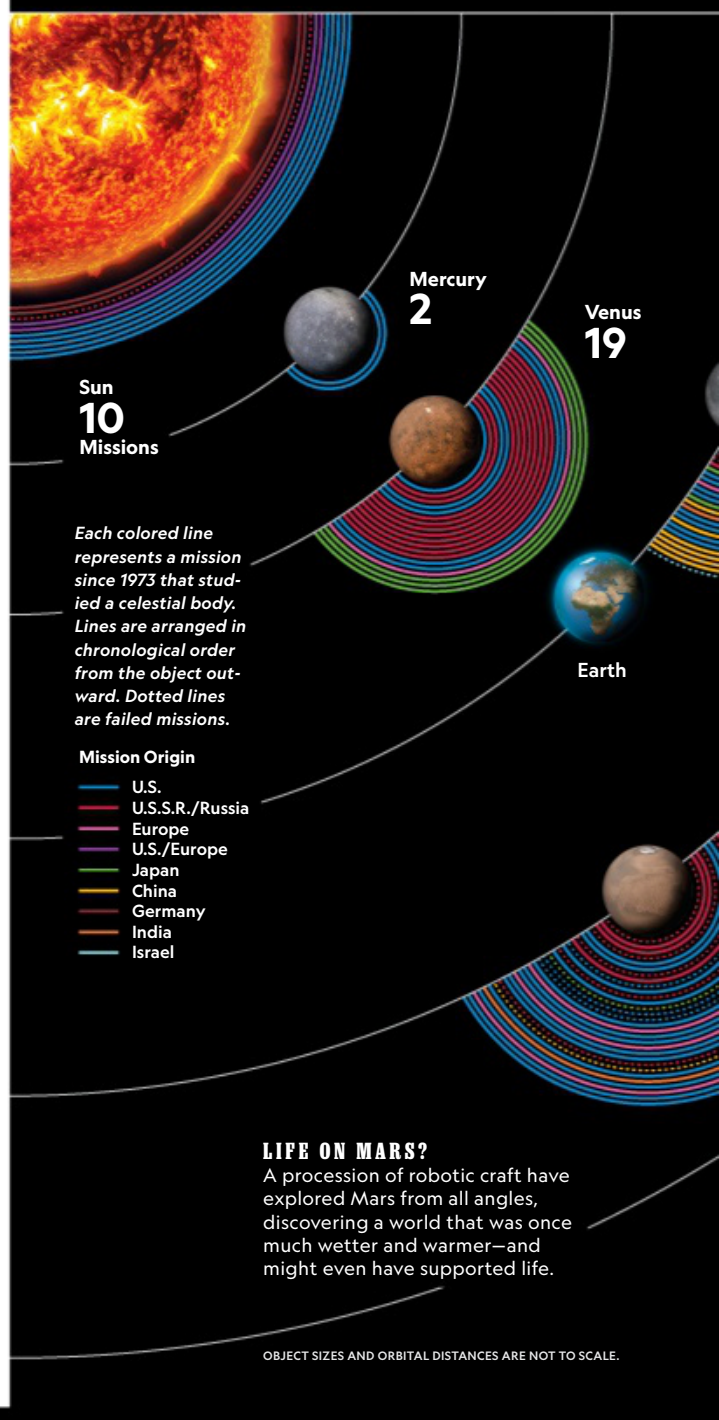
Space agencies have sent probes, with no people on them and thus no need to worry about human safety, to visit far-flung places in the solar system. Spacecraft have explored 60 other moons and even set down on one, Saturn's Titan. On our own moon, robotic rovers have left tracks at four sites.

China made history earlier this year by setting its Chang'e 4 lander on the moon's far side.

The first private lander to reach the moon crashed in April, but the Israeli nonprofit behind it quickly announced plans to try again.

Not to be outdone, the U.S. intends to send a series of landers with technology to lay the groundwork for astronauts to return.

INNER SOLAR SYSTEM



LIFE ON MARS?

A procession of robotic craft have explored Mars from all angles, discovering a world that was once much wetter and warmer—and might even have supported life.

OBJECT SIZES AND ORBITAL DISTANCES ARE NOT TO SCALE.

ed the moon in 1972.
stations orbiting Earth
ther into space to take
solar system up close.

LIVING AND WORKING WHILE ORBITING EARTH

International crews have continued to conduct research on Earth-orbiting stations, while for 30 years NASA's reusable space shuttles carried crew and cargo on a variety of missions.

ASTEROID BELT

OUTER SOLAR SYTEM

THE MOON AND ITS PROSPECTS

Space companies are determining whether there's money to be made on Earth's nearest neighbor through projects like mining, commercial travel, and colonization.

Moon 25

Deimos

Phobos 6

Mars 30

Asteroids 11

ASTEROID ENCOUNTERS

Filled with protoplanetary bodies, the asteroid belt holds clues to how our solar system and planets formed. Probes have visited and collected samples from asteroids.

TURBULENT JUPITER

The first missions to the planet revealed a ball of violent, swirling gases. Some of Jupiter's moons have been studied for the potential to harbor life.

Callisto 4
Ganymede 5
Europa 5
Io 5
Thebe
Amalthea 3
Metis
Adrastea

Jupiter 8

Saturn 4

Pan
Daphnis
Atlas 2
Prometheus 2
Pandora 2
Epimetheus 2
Janus 2
Mimas 3
Methone
Pallene
Enceladus 3
Tethys 3
Telesto 2
Calypso 2
Dione 3
Helene 3
Rhea 3
Titan 4
Hyperion 3
Iapetus 3
Phoebe 2

Uranus 1

Cordelia
Ophelia
Bianca
Cressida
Desdemona
Juliet
Portia
Rosalind
Belinda
Puck
Miranda
Ariel
Umbriel
Titania
Oberon

Neptune 1

SATURN SOJOURN

Few missions have visited the planet, but Cassini arrived in 2004 and explored for 13 years; data are still being processed.

KUIPER BELT

Reaching the most distant bodies in our solar system, the New Horizons spacecraft was the first to visit Pluto; it then flew on to explore Ultima Thule.

Naiad
Thalassa
Despina
Galatea
Larissa
Proteus
Nereid
Triton

Pluto 1

Charon
Styx
Nix
Kerberos
Hydra

Ultima Thule 1

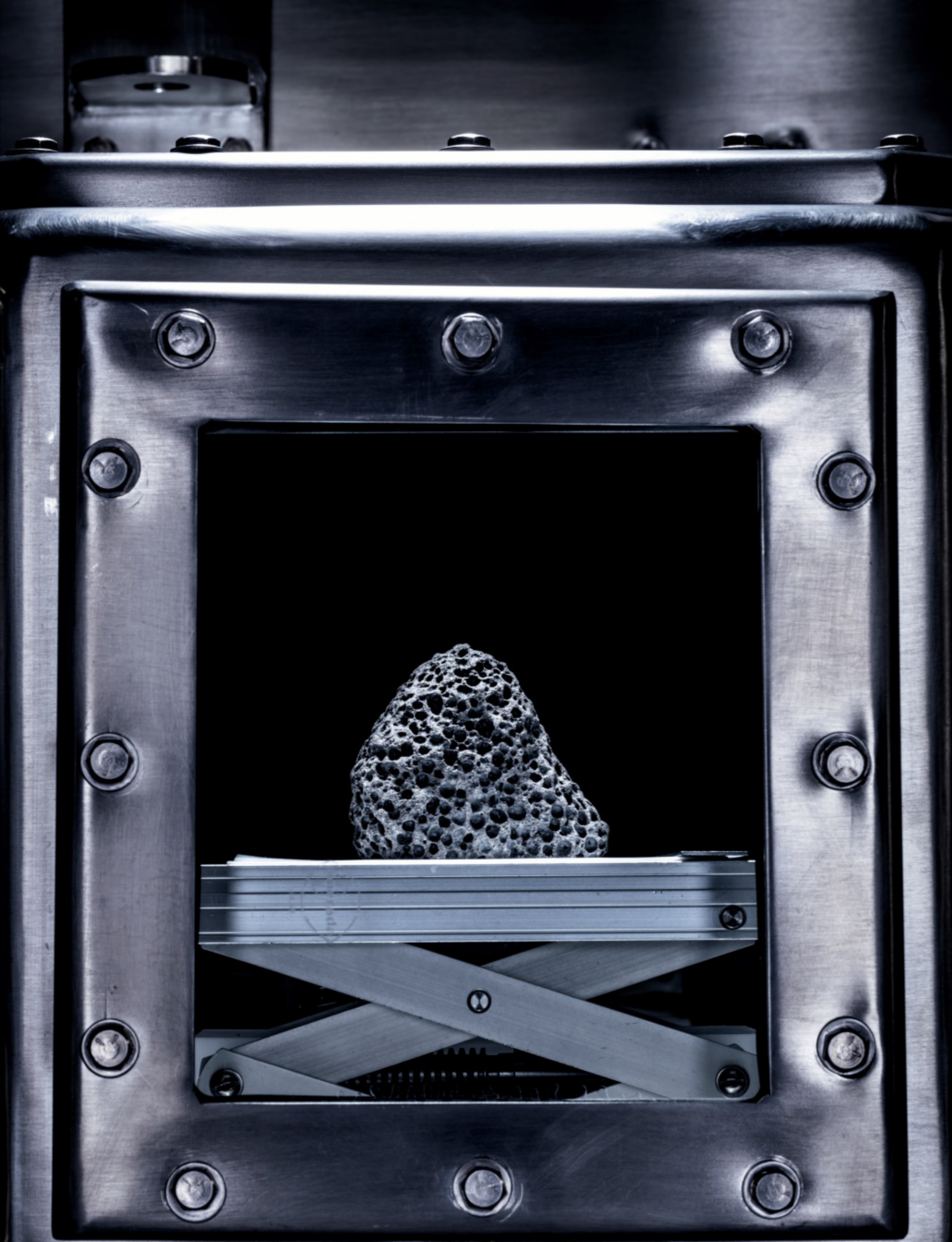
HALLEY'S COMET

On an eccentric orbit that travels past Neptune, Halley returns to the inner solar system every 76 years. Various craft studied its last visit, in 1986.

Halley's comet 5

Comets 11

NGM ART. MATTHEW TWOMBLY; ALEXANDER STEGMAIER. SOURCES: NASA; ASIF SIDDIQI, FORDHAM UNIVERSITY; JONATHAN McDOWELL, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS; USGS ASTROGEOLOGY SCIENCE CENTER



T MINUS

WHAT WE TOOK

LEFT: A piece of Lunar Sample 15016, a form of basalt, is preserved in a stainless steel cabinet filled with flowing, purified nitrogen gas.

ASTRONAUTS COLLECTED ROCKS, PEBBLES, SOIL, AND DUST. THEY ALSO TOOK PERSONAL ITEMS TO SPACE THAT REFLECTED THEIR INTERESTS, BELIEFS, AND PASSIONS.

NASA JOHNSON SPACE CENTER

Over four years, NASA astronauts hauled 842 pounds of moon rocks back to Earth. But the most profound souvenirs weigh nothing: images of Earth. Apollo 8 astronaut William Anders snapped an iconic one on Christmas Eve in 1968, showing our blue planet suspended in darkness near the moon's sterile, cratered horizon.

Astronauts didn't just take photos and collect moon rocks, they also carried an array of objects from Earth into space with them.

John Young (Gemini 3) notoriously smuggled aboard a corned beef sandwich and shared it with Gus Grissom, his crewmate. Grissom pocketed it when crumbs began to float around the cabin.

Buzz Aldrin (Apollo 11) took wine, bread, and a chalice to celebrate Communion. His crewmate Neil Armstrong carried a piece of the Wright Flyer's wooden propeller. Alan Shepard (Apollo 14) used a sock to hide a six-iron clubhead, which he attached to a tool handle to hit two golf balls on the moon. Charles Duke (Apollo 16) packed a family photo and left it in the Descartes highlands.

Perhaps the most poignant memento on the lunar surface is a small aluminum human figure, placed there by David Scott during Apollo 15. It rests near a placard bearing the names of 14 fallen astronauts and cosmonauts.

THIS CHALICE WAS USED BY
COL. EDWIN E. ALDRIN, JR.
IN CELEBRATING HOLY COMMUNION
ON THE MOON
APOLLO 11 TRANQUILITY BASE
JULY 20, 1969

One of NASA's most requested space photos, this view of Earth, known as Blue Marble, was taken in 1972 from about 18,000 miles away, as Apollo 17 was traveling to the moon.

NASA JOHNSON SPACE CENTER

TOP LEFT

Aboard Gemini 6, Walter Schirra tootled "Jingle Bells" on this harmonica as Thomas Stafford shook sleigh bells, making the first music in space on December 16, 1965.

SMITHSONIAN'S NATIONAL AIR AND SPACE MUSEUM

BOTTOM LEFT

After landing on the moon, Buzz Aldrin drank consecrated wine from this three-inch goblet, which is still used by his former church near Houston.

WEBSTER PRESBYTERIAN CHURCH

T MINUS

IN POP CULTURE

RIGHT: In 1967 Mattel introduced Major Matt Mason, one of the first realistic space action figures. His suit was based on a prototype.

FROM TV SHOWS TO MOVIES, TOYS, FOOD, AND THE WAY WE EXPRESS OURSELVES, SPACE CONTINUES TO HAVE A HOLD ON OUR IMAGINATION.

As the space race boomed, it catapulted its aspirations into the zeitgeist—and transformed the way we live.

Sputnik inspired replicas and songs. *Life* magazine published exclusive stories on the lives of the celebrated Mercury Seven, the United States' first astronauts. Seattle built the Space Needle for the World's Fair. Stanley Kubrick created *2001: A Space Odyssey*. The space age flourished in movies, TV, music, architecture, and design, where the sleek, aerodynamic lines of rockets inspired the look of cars and trains.

Space is still lodged in popular culture. The NASA logo appears everywhere, from tattoos to Vans high-tops. We've had *Star Trek*, *The Jetsons*, *Mork & Mindy*, *Star Wars*, and the current spate of Mars movies and space-themed TV shows. Also: the Houston Astros and the Houston Rockets, Space Camp, antigravity ballpoint pens, astronaut ice cream, the moonwalk, and Space Mountain.

Concepts like "the right stuff," "moon shot," and "light-years" figure into everyday conversation. Your first day back after vacation might be filled with "reentry" problems. Your craft-brewed IPA might taste like "rocket fuel" or even use those words as its name. And, on discovering a distressing situation, you might calmly say, "Houston, we have a problem."

LEFT

The January 10, 1967, issue of *Look* magazine featured this Norman Rockwell painting of how it might look when Neil Armstrong set foot on the moon. Rockwell, a stickler for accuracy, consulted experts and collaborated with a space artist to create this vision.

© 1967 ARTWORK COURTESY THE NORMAN ROCKWELL FAMILY AGENCY/SMITHSONIAN'S NATIONAL AIR AND SPACE MUSEUM

RIGHT

In Russia cosmonauts are often depicted on memorabilia. This poster, headlined "World's First," heralds the 20th anniversary of Valentina Tereshkova's solo flight in 1963, when the 26-year-old former textile worker and skydiver became the first woman in space.

DAVID POLLACK, GETTY IMAGES

LEFT

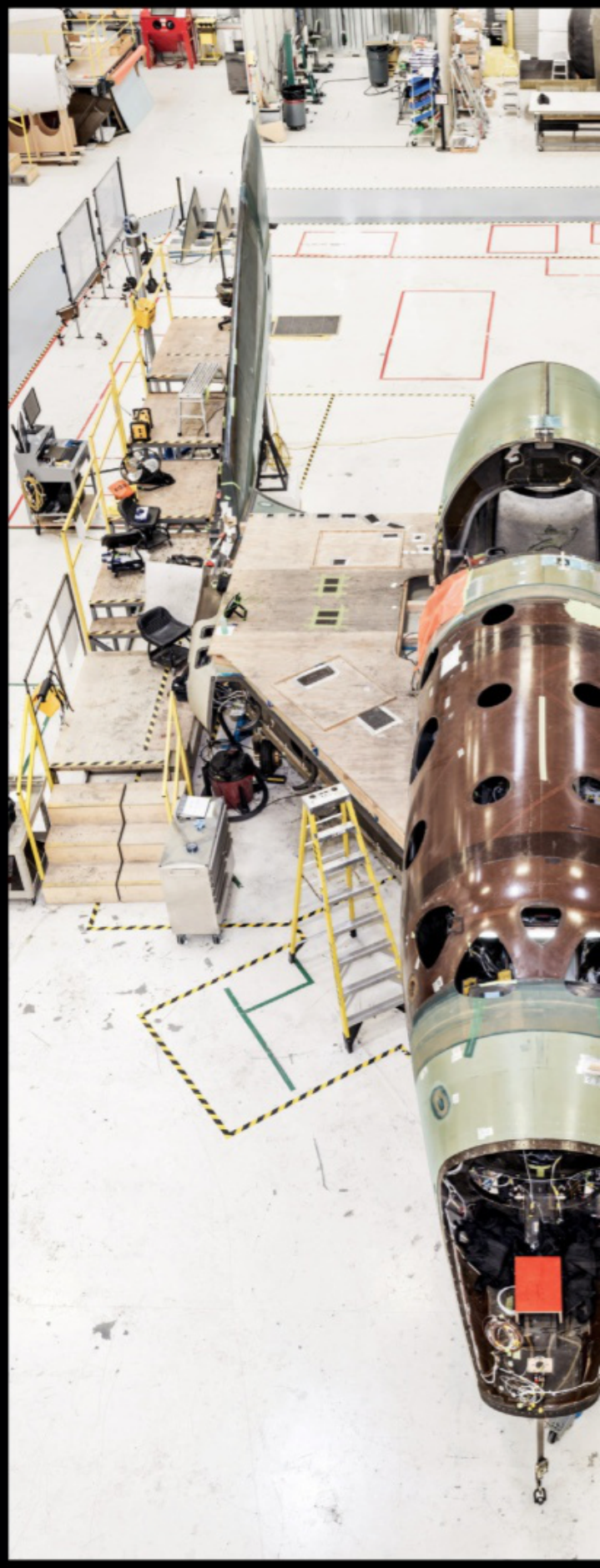
Project Mercury, which rocketed U.S. astronauts to space six times from 1961 to 1963, inspired many objects that celebrated the historic achievement. This metal lunch box shows an accurate cutaway view of the cone-shaped, single-seat Mercury capsule.

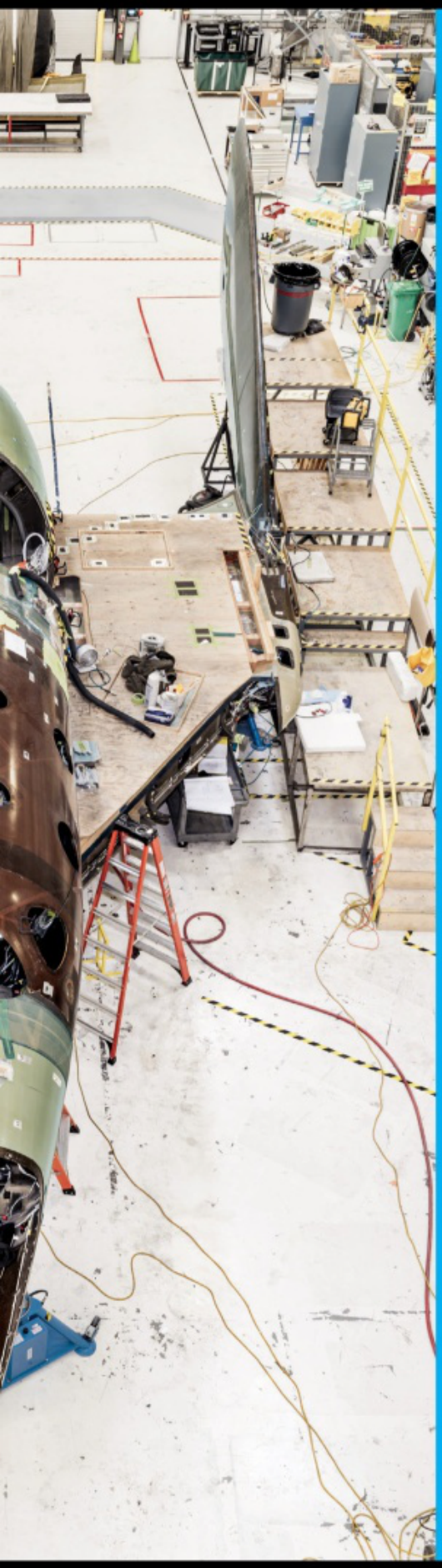
PRIVATE COLLECTION OF SUSAN N. FREEMAN

ABOVE

Billed as "the first space age–inspired car," the Firebird III, built by General Motors, was powered by a gas turbine engine and sported seven fins. The 1958 concept car had a computer, electronic controls, and a joystick to accelerate, brake, and steer.

GENERAL MOTORS HERITAGE CENTER





LIFTOFF!

WHAT'S NEXT

LEFT: Virgin Galactic's VSS *Unity,* shown in 2015, has flown higher than 50 miles, the distance NASA considers the beginning of space.

IT MAY SEEM AS IF WE'VE BEEN GOING NOWHERE FOR DECADES. BUT A NEW AGE OF SPACE TRAVEL IS COMING, MIXING EXPLORATION WITH A RACE FOR PROFITS.

BY SAM HOWE VERHOVEK

PHOTOGRAPHS BY DAN WINTERS

hen human beings stepped on the moon 50 years ago this month, it was one of history's most astounding moments, and not just because our first visit to another world was among humanity's greatest scientific achievements or because it was the culmination of an epic race between two global superpowers, though both were true. The *New York Times* put a poem by Archibald MacLeish on the front page, and newscaster Walter Cronkite, "the most trusted man in America," would come to say that people living 500 years in the future would regard the lunar landing as "the most important feat of all time." ¶ The ultimate significance, however, was not that the race had ended or even that a once unimaginable milestone had been attained. ¶ This achievement was really just the beginning. ¶ The beginning of a new era in humanity's vision of its horizons, of the places we could explore and might even inhabit. Having started as a landfaring species, expanded our reach to the entire planet when we became seafaring, and conquered the atmosphere above Earth when powered flight made us skyfarers, we were now destined to be pilgrims in a vast new realm. We were spacefarers—and soon, as this seminal triumph helped us get over what celebrated scientist and writer Isaac Asimov called our "planetary chauvinism," we would become an extraplanetary species. "Earthlings" would no longer be sufficient to describe who we were. ¶ All this is what was widely expected, amid the euphoria and wonder on July 20, 1969, when *Eagle,* Apollo 11's lunar module, touched down on the moon's surface. The greatest journey starts with a single step. A small step for one man; a giant leap for all of humankind. ¶ The head of the U.S. National Aeronautics and Space Administration, Thomas O. Paine, was soon aiming for Mars, and not just as a someday goal but with a detailed itinerary laid out in *National Geographic*. Depart: October 3, 1983. Crew of 12, split between two 250-foot-long spacecraft fired by nuclear rockets. Enter Mars orbit: June 9, 1984. Eighty days of exploration on the Martian surface. Return to Earth orbit: May 25, 1985. ¶ The very act of reaching the moon somehow exalted the human race, yielding confidence that we would indeed push deeper into space. "Wherever we went, people, instead of saying, 'Well, you Americans did it,' everywhere they said, 'We did it!'" recalled Michael Collins, the pilot of Apollo 11's command module. "We humankind, we the human race, we people did it."

The weather on Mars can vary dramatically, requiring a space suit that makes it possible for astronauts to venture out into temperatures as low as minus 80°F and as high as 70°F. Under development by a lab at the University of North Dakota with funding from NASA, this experimental suit is made from 350 components.

NASA KENNEDY SPACE CENTER

Sunrise is still a few hours away, and as the bus cuts a lonely path through miles of remote steppe in southern Kazakhstan, its headlights occasionally illuminate for the briefest of moments a giant faded mural or a chipped tile mosaic. These stylized works of art show the ravages of baking summers and bitter winters. They adorn huge, rusting, abandoned buildings, and they celebrate the decades-old glories of a space program in a nation that no longer exists: the Soviet Union.

Finally, after miles of this *Twilight Zone* landscape of Cold War detritus, the bus makes a sudden turn down a gated lane and arrives at a giant, banged-up structure that is definitely not abandoned. Well-armed Russian and Kazakh security officers in camouflage gear seem to have the place surrounded, and it's bathed in floodlights. Inside this hangar is a gleaming new rocket ship.

I've come to the Baikonur Cosmodrome because, just shy of the 50th anniversary of the moon landing, it's the only place on the planet where I can watch a human blast off to space. In turn, the only place in the universe these people can fly to is the International Space Station, some 250 miles above Earth, which is barely one-thousandth of the distance to the moon.

For the past eight years, ever since NASA retired the space shuttle, the only way it has been able to get an American astronaut to the space station has been to hitch a ride with its Russian counterpart, known as Roscosmos, at roughly $82 million for a seat up and back down.

Fifty years on from the moon landing, this is where we are in space, if by "we," we mean human beings. Which sure sounds like basically nowhere, at least as measured by the yardstick of 1969's great expectations. Twelve people—all Americans, all men—have stepped on the moon, none since 1972, and other than on Earth-orbiting space stations, no human has set foot anywhere else in the universe.

Measured another way, of course, we're doing extraordinary things in space.

We've sent uncrewed probes to explore all the other planets in our solar system, yielding astonishing photographs and troves of data. The twin Voyager spacecraft have literally sped across the solar system and into interstellar space, the first human-made objects ever to do so. They're more than *11 billion miles away* and still communicating with us.

Because the Voyagers could travel forever into the void and both the sun and the Earth have an expiration date (don't worry, it's a ways off), it's conceivable that one day these sedan-size eternal sojourners will be the only evidence that we ever existed. Yet it's also conceivable that a successor species to us will have long gone interstellar by then, hopefully granting us some recognition for their feat.

And if they do, they may well point to this moment in time—the late 2010s, the early 2020s—as the "inflection shift," which is how Jim Keravala, a physicist who has overseen satellite launches on Russian, European, and U.S. rockets, characterizes the frenzy of activity in the commercial space industry today.

We are, Keravala says, at the dawn of "the true beginning of the era of space settlement and humanity's future off-world." (Keravala now heads OffWorld, a company that intends to deploy millions of robots to turn the inner solar system into a "better, gentler, greener place for life and civilization.")

Keravala's intriguing prediction is highly debatable, in part because that old industry chestnut—"space is hard"—happens to be true; setbacks and delays are virtually always part of the march to progress.

But it's undeniable that something big is going on in space. Two U.S. companies, SpaceX and Boeing, are moving closer to certification of their spaceship models, putting NASA "on the precipice of launching American astronauts on American rockets from American soil," in the words of NASA administrator Jim Bridenstine. These ships—which are to Apollo's cramped modules as a Boeing 787 Dreamliner is to a prop-driven airliner of the 1950s—may carry out crewed missions by late this year or early next year.

Meanwhile, spacecraft built for two other private companies, Virgin Galactic and Blue Origin, have also made major strides, bringing us ever closer to a novel era of space tourism. To begin, they will shoot well-heeled customers up to an elevation of 60-odd miles, to the edge of outer space, where the clientele will experience zero-gravity weightlessness and see the black void of the universe and the blue curvature of the Earth. All this can be yours for a mere $200,000 or so at present—though both companies say prices will drop rapidly and options expand as they bring more rocket ships on line.

GETTING INTO ORBIT

In the 1950s the Soviet Union and the U.S. built the first launch sites. Other countries followed in the 1970s. Today Rocket Lab has the only private site, but others are under construction. Many of the 22 active ports are in the southern regions of countries because Earth's surface rotates faster near the Equator, giving launches a boost.

Blue Origin is also shaking up the race to put humans back on the moon, announcing in May that it's building a lander named Blue Moon. The robotic vehicle will be able to haul up to seven tons of cargo and could put astronauts on the lunar surface by 2024.

The action in space is hardly confined to American companies or Russia's program. In January, China boasted that it "opened a new chapter" in lunar exploration by soft-landing an uncrewed spaceship on the far side of the moon, the first time a vehicle had ever touched down there. That spacecraft deployed a rover bearing a "mini-biosphere," designed to test whether fruit flies and a variety of plants and seeds can work together to create food in lunar conditions. China announced in April that it intends to build a research station on the moon's south polar region within the next decade, although the nation's space agency remains mum about how soon it might try to land "taikonauts," as its astronauts are known, on the lunar surface.

In Israel, which sees itself as a plucky "start-up nation," there were both cheers and tears in April, when a nonprofit consortium called SpaceIL made history as the first private concern to orbit the moon. But its bid to make Israel the fourth country to soft-land an object there had a hard ending: SpaceIL's small spacecraft called Beresheet (Hebrew for Genesis, or "in the beginning") instead crashed on the lunar surface and

NEXT PHOTO

A technician installs components on the CST-100 Starliner, a new capsule engineered by Boeing that can carry as many as five passengers to the International Space Station. Designed to set down on the ground, rather than on water, it has parachutes to brake its descent and airbags to cushion its landing. Each capsule will be able to be used up to 10 times. Boeing plans a crewed test launch within a year.

ACTIVE PORTS WITH AT LEAST ONE ORBITAL SPACE LAUNCH BETWEEN 2008 AND 2018 SHOWN.
SOREN WALLJASPER, NGM STAFF. SOURCE: THOMAS G. ROBERTS, CSIS AEROSPACE SECURITY PROJECT

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In remote New Zealand, from a launchpad adjacent to a giant sheep pasture, a company called Rocket Lab is sending innovative, low-cost rockets bearing satellites into low Earth orbit.

At the edge of Dubai, where Emirates airline has forged a massive global crossroads for air travelers out of once empty desert, an entirely new and even more colossal airport under construction is being billed as the world's first "cosmotropolis." Authorities say it will be capable of handling rocket ships and hyper- and supersonic aircraft as well as conventional jet airliners.

And in Japan, JAXA, the official space agency, announced in March that it was working with Toyota to develop a crewed moon rover that would enable astronauts to travel 6,000 miles on the lunar surface.

Much of today's rocketry is fueled by an intense competition among a few superbillionaires whose ambitions (and egos) appear to be out of this world.

Their spacecraft are different from yesteryear's because they are not being developed purely for scientific exploration. These spacecraft are intended to make money by fulfilling the expensive wishes of wannabe astronauts or harvesting valuable resources through mining on asteroids; by flying people quickly between any two points on Earth; and indeed, as Keravala suggests, by ultimately making us a multiplanetary species.

Many of these space titans have a clear vision of where they're taking the rest of us, but collectively we have barely begun to discuss the ethics—or wisdom—of it all. If, as the relentless evangelist for space and commerce Jeff Bezos has insisted, the solar system can easily support "a trillion humans," among whom we would have "a thousand Einsteins and a thousand Mozarts," should we then heed the Amazon founder's call to go forth and multiply in the firmament? (And if so, will Amazon Prime deliver?)

At the same time, there is something very curious about the lofty slogans, visions, and mission statements that private space companies feature in their promotional materials: Many contend that going to space is actually about … saving the Earth—and making it a better place.

"We open space to change the world for good" (Virgin Galactic, founded by billionaire Richard Branson). "To preserve Earth … we must go to space to tap its unlimited resources and energy" (Blue Origin, Bezos's company). "We open access to space to improve life on Earth" (Rocket Lab). "Imagine most journeys taking less than 30 minutes, with access to anywhere in the world in an hour or less" (SpaceX, brainchild of billionaire Elon Musk, who says space travel will make such Earth-to-Earth trips feasible).

Why are we in space? Fifty years ago, it was easy to answer the question. To reach the moon! Sure, discovery, generally; and national prestige, specifically. To issue a grand proclamation of goodwill: "We came in peace for all mankind." Everybody knew the point was to step on the moon, return safely, and crow about it.

Ask that question today, however, and you may get any of a dozen answers. These are worth examining, because you can't explore whether we should be in space without a sense of what we are doing there—or aiming to do.

Outside the hangar in Kazakhstan, I step off the bus along with the rest of my group—a large crop of reporters, mostly Russians and a few Canadians. We stand around and stomp our feet for a while, as it's cold on this early December day—seven degrees Fahrenheit with a rattling wind that has a well-below-zero feel to it.

We are at the edge of a security barrier—my group on this side, wielding cameras and notebooks, the security guys on the other side, gripping guns and speaking purposefully into walkie-talkies tucked into the shoulders of their uniforms. The rocket ship is on its side on a flatbed railcar, four conical boosters at the base of a white cylinder, with a brightly painted Russian flag at the top. As it sounds a low whistle, the train slowly pulls out, headed to the launchpad a few miles away.

There's some drama to the launch because the previous one, in October, was aborted just 57 miles up when a sensor malfunction prompted the crew capsule to separate from the rocket and booster assembly. NASA astronaut Nick Hague and Russian cosmonaut Alexey Ovchinin averted disaster with a harrowing emergency landing.

"The crew was lucky," Anne McClain, an Army lieutenant colonel, Iraq war veteran, and helicopter pilot, explained in a NASA-TV news conference. "But every crew that makes it to orbit is lucky. Spaceflight's not easy."

McClain should know: A NASA astronaut,

Much of today's rocketry is fueled by an intense competition among a few superbillionaires whose ambitions are not purely scientific: Their spacecraft are intended to make money.

she's on the launch I'm at the Cosmodrome to see.

Now Roscosmos says the problem is fixed and this Soyuz rocket launch will be trouble free. And indeed, from behind a glass wall in a special quarantine zone, McClain and the other two crew members are telling us—in English, in Russian, and in French—that they share that faith. Thumbs-up all around. A Russian Orthodox priest, as is customary these days, blesses the crew and the ship with holy water in two brief but solemn ceremonies; he even blesses the assembled reporters, a touch I cannot help but appreciate in this era of relentless attacks on the free press.

At Baikonur, reporters witness a launch from a distance of just under a mile, which is significantly closer than at Cape Canaveral, where they are kept about three miles away. It's a mesmerizing and profound spectacle: the huge burst of orange flame at the rocket's base on ignition, the engine roar, the rumbling, shaking ground. The awe I feel is intensified by the knowledge that at the very tip of the ship, three of my fellow human beings are trusting that all will be well as they are shot straight up into the sky.

The number of human beings living in space is about to double—from three to six. In less than three weeks the three already at the space station would come home, and the human census beyond Earth's atmosphere—on the moon, on all the other planets in the solar system, on all those other moons, on asteroids, and in or on the many things that humankind has built and launched into orbit over six decades—would drop back down to three. The other 7.6 billion or so of us? We're still earthbound.

Soon, however, the United States could have not one but two American-made options for getting astronauts to space, finally severing NASA's sole dependence on Russian Soyuz rockets. These new spaceships are a first step toward much longer range missions: to the moon, to asteroids, and even to Mars.

And so, a few months after the surprisingly moving, even mystical experience of watching the Soyuz liftoff, I find myself some 170 feet above the ground on a gorgeous blue-sky Florida day, the Atlantic Ocean sparkling a half mile away.

I'm at Cape Canaveral Air Force Station, atop Space Launch Complex 41, whose history dates to 1965, when it began launching Titan rockets for the space programs that preceded Apollo. It's eventually going to launch Boeing's CST-100 Starliner capsule, which will carry as many as five passengers at a time to the International Space Station.

The first thing I notice after stepping off the elevator are four parallel zip lines leading to the ground at the very edge of the launch complex.

"If you're an astronaut, you really, really don't want to be taking that ride," says Tony Taliancich, director and general manager of launch operations for ULA, a launch alliance that is a joint venture of Boeing and Lockheed Martin. Taliancich, imposingly built but perpetually smiling during my tour of his bailiwick, explains that these 1,300-foot-long zip lines are a critical part of the escape system, in case a last-minute explosion, fire, or other emergency provokes an abandon-ship order.

They bring to mind the fire that erupted in the cabin of the Apollo 1 spacecraft in January 1967, a tragedy that quickly claimed the lives of three astronauts at Launch Complex 34 near here, now a memorial site honoring the men "who made the ultimate sacrifice so others could reach the stars."

They're also a useful reminder: Despite the strides NASA has made in its perpetual quest to make spaceflight safer, it's still a dangerous business. Our astronauts are essentially stepping on top of a bomb whenever they climb into the capsule of a spacecraft, a bomb they trust will go off in a controlled manner.

Of the 135 space shuttle flights, two ended in disaster, claiming seven lives each. If we

accepted that failure rate in the commercial airliners we rely on in this country, we'd be tolerating more than 500 crashes *every day*.

Taliancich, who spent much of his career in Air Force space-launch operations, shows me where the Starliner crew capsule will fit and points out the entryway into a sealed chamber that will ensure the cabin remains pristine when the astronauts enter it.

I'd seen a Starliner an hour or so earlier in a nearby assembly plant. More accurately, I'd seen the upper and lower halves of the conical capsule without their outer heat-shielding shells, revealing the mind-boggling spaghetti mix of tubes, wires, and electrical cables that go into a spacecraft.

With improved seats and larger windows, as well as interior LED "mood lighting," this spacecraft's cabin is clearly a 21st-century upgrade from an Apollo capsule. While the lighting feature sounds a bit whimsical, it's anything but. Eventually, advanced lighting may help regulate astronauts' circadian rhythms and sleep cycles as well as their emotions, one of several critical challenges that must be overcome before NASA or any other space agency can send humans on the months-long trip to Mars.

Thomas O. Paine, NASA's chief in 1969, thought we'd have set foot on Mars and the moons of Jupiter by now. His prediction still may come true—by the 100th anniversary of Apollo 11.

Just when will that Mars trip finally occur?

NASA does not have a specific timeline for human exploration of the red planet. In the meantime, the focus is on sending astronauts back to the moon as a way to test both human and spacecraft capabilities.

"The moon is the proving ground; Mars is the horizon goal," NASA's Bridenstine said in March during a presentation at Cape Canaveral unveiling the space agency's proposed budget.

To establish a presence on the moon, astronauts will need to look at ways of extracting water, oxygen, and helium—as fuel for human and machine alike. (Helium-3, a gas thought to exist in significant quantities there, could be used for future nuclear fusion–propelled rockets.) The moon could also wind up as a staging ground for launches to elsewhere: Since it has only one-sixth of Earth's gravity, much less energy is needed to send a ship beyond the moon's pull than here on our planet.

Space-exploration advocates are unhappy with the budget, saying it provides for a too-slow timetable for getting to Mars. Bridenstine counters that it incentivizes private industry to speed up capabilities for a crewed landing, and he frequently invokes the frenemy of comic character Charlie Brown to make his case that the path to Mars is genuine: "This is not Lucy and the football anymore," he says. The Starliner—or the SpaceX version, called Crew Dragon, or both—may well be the future of human space exploration.

Still, let's return to Earth and reiterate a few things about where we are today.

We're manifestly not where many thought we'd be 50 years on, and certainly not where NASA's Paine said we could be, which was not only Mars but also the moons of Jupiter and who knows where else. We're not even back on the moon. Paine, who died in 1992, believed that thousands of us would be enjoying lunar vacations in his lifetime.

"There's no question we can reduce the cost of travel to the moon to the cost of traveling through air today," Paine told *Time* magazine shortly before the Apollo 11 landing.

It's certainly possible that the big predictions of 1969 will come true—but closer to the 100th anniversary of the lunar landing, with this half-centennial milestone marking the beginning of Space Age 2.0.

Musk, who says he intends to move to Mars someday, is the most aggressive on a time frame. He's pegged 2024 for a crewed SpaceX spaceship to land on Martian soil, a projection widely dismissed as hopelessly—or recklessly—optimistic. In April a U.S. government–mandated

independent analysis concluded that it was "infeasible under all budget scenarios and technology development and testing schedules" for NASA to send humans to Mars before 2034. Other Mars advocates say the early 2040s is more like it.

Landing and exploring: doable. But, to be clear, many experts consider bold projections of celestial living to be, pardon the pun, lunacy.

I ran into Bill Nye, the popular and pithy Science Guy of television fame and CEO of the Planetary Society, at a space conference last year in Washington, D.C., and he rolled his eyes at the idea that Mars will eventually be "terraformed" for human habitation.

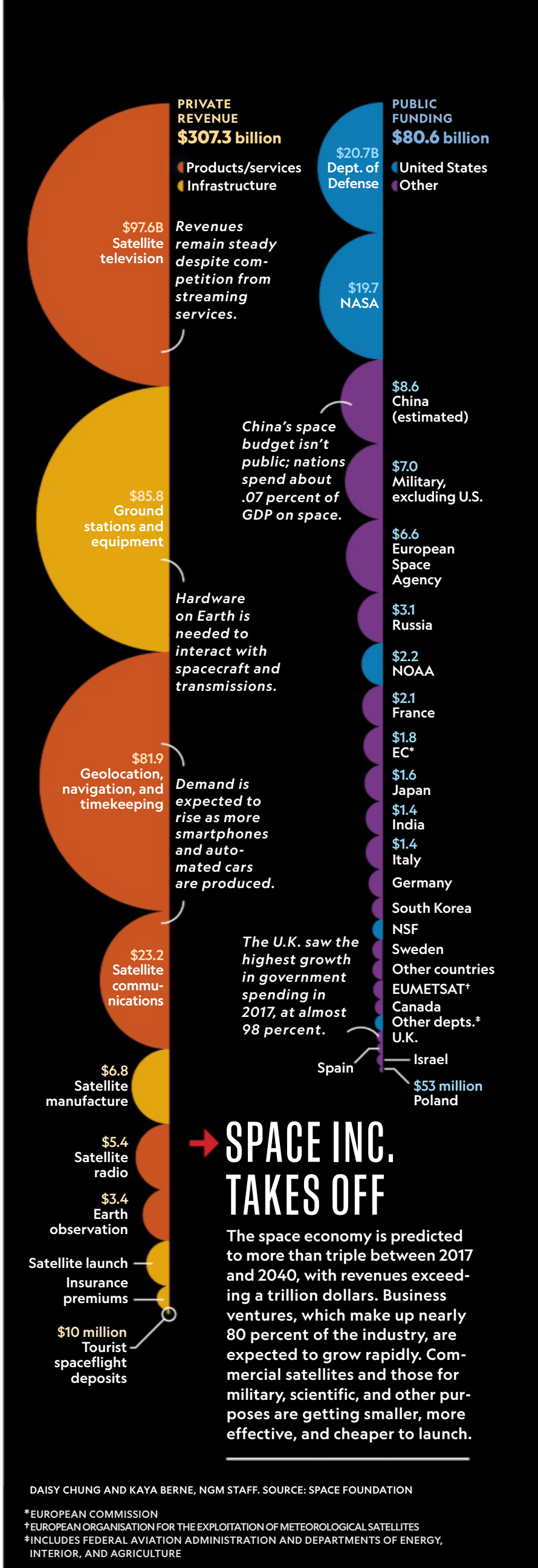
"It's incredibly cold, there's hardly any water, there's no food, and by the way, there's nothing to breathe," Nye said. "And the smell in your space suit—bring all the Febreze you can pack, because you're going to be craving it on Mars." (Nye does favor missions to the red planet, just not permanent habitation.)

The other thing to reiterate: Anything we can do, our robots can do better (in space, that is), with the exception of capturing the majesty of what's there as only an artist or poet could. We've done amazing things in space without sending people there, and not just because we've launched all those satellites into orbit that have propelled quantum leaps in how we communicate, navigate, prognosticate—on the weather, anyway—and do countless other things here on Earth.

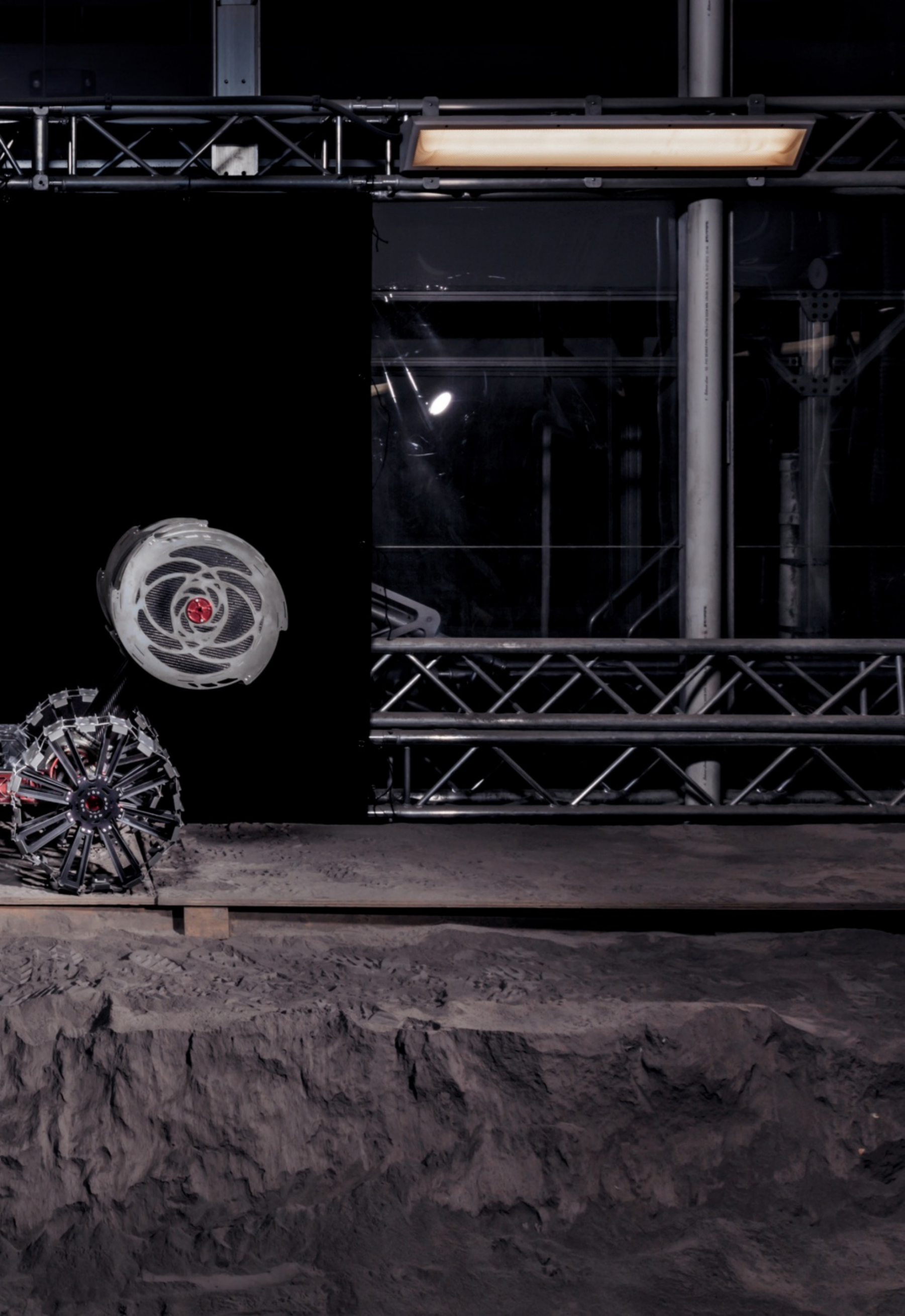
Probes keep sending back detailed images, and soon we will be launching a telescope into space so powerful that it will enable us to peer at faraway objects whose light originated billions of years ago. This may help us answer questions about the early universe and perhaps even locate life elsewhere in the cosmos.

Those remarkable twin Voyager probes, launched in 1977 and fueled by tiny nuclear-powered generators, are still returning data about the environment around them, sent by a radio transmitter that uses about as much power as a standard light bulb. That makes for a faint signal, but here on Earth we can "hear" what the Voyagers have to say because we've developed antennas sensitive enough to pick up the signal.

"Amazing" strikes me as far too limited a word to describe our most far-flung emissaries, which indeed are diplomats in that they each carry the legendary "Golden Record" of earthly sounds,


PRIVATE REVENUE
$307.3 billion
Products/services
Infrastructure
PUBLIC FUNDING
$80.6 billion
United States
Other
$97.6B Satellite television
Revenues remain steady despite competition from streaming services.
$20.7B Dept. of Defense
$19.7 NASA
$8.6 China (estimated)
China's space budget isn't public; nations spend about .07 percent of GDP on space.
$85.8 Ground stations and equipment
Hardware on Earth is needed to interact with spacecraft and transmissions.
$7.0 Military, excluding U.S.
$6.6 European Space Agency
$3.1 Russia
$2.2 NOAA
$2.1 France
$1.8 EC*
$1.6 Japan
$1.4 India
$1.4 Italy
Germany
South Korea
NSF
Sweden
Other countries
EUMETSAT†
Canada
Other depts.‡
U.K.
Israel
$53 million Poland
Spain
$81.9 Geolocation, navigation, and timekeeping
Demand is expected to rise as more smartphones and automated cars are produced.
$23.2 Satellite communications
The U.K. saw the highest growth in government spending in 2017, at almost 98 percent.
$6.8 Satellite manufacture
$5.4 Satellite radio
$3.4 Earth observation
Satellite launch
Insurance premiums
$10 million Tourist spaceflight deposits
SPACE INC. TAKES OFF
The space economy is predicted to more than triple between 2017 and 2040, with revenues exceeding a trillion dollars. Business ventures, which make up nearly 80 percent of the industry, are expected to grow rapidly. Commercial satellites and those for military, scientific, and other purposes are getting smaller, more effective, and cheaper to launch.
DAISY CHUNG AND KAYA BERNE, NGM STAFF. SOURCE: SPACE FOUNDATION
*EUROPEAN COMMISSION
†EUROPEAN ORGANISATION FOR THE EXPLOITATION OF METEOROLOGICAL SATELLITES
‡INCLUDES FEDERAL AVIATION ADMINISTRATION AND DEPARTMENTS OF ENERGY, INTERIOR, AND AGRICULTURE

To excavate, haul, and dump the layer of dust and rocks found on the surface of the moon, NASA designed a mobile robotic platform called RASSOR, shown here at the Kennedy Space Center. To operate in a low-gravity environment, it has counter-rotating bucket drums that are not dependent on traction or weight.



music from around the world, and greetings from Jimmy Carter (the U.S. president at launch time) to inform and entertain any sentient aliens that might encounter them.

That the Voyagers are still hurtling through the heavens illustrates a serious point.

Humans simply couldn't make this trip. With our nettlesome need for air and food and water, protection from cosmic radiation or solar flares, not to mention stimulation so we don't go mad on the long journey to wherever, it's worth asking: Why go at all? Why go, especially when there is basically nothing to be done that a robotic probe cannot do more efficiently, quickly, cheaply, and safely than a human being? Let's face the truth: From mining asteroids for rare materials to snapping photos of other planets, uncrewed probes are better suited to the job.

Yet this raises the question of whether it's important for us to explore. No uncrewed journey—even one of billions of miles—will ever generate quite the thrill, suspense, or awe of a man putting the first footprint on our nearby moon—or a woman doing so someday on Mars. (The next American to step on the moon, Bridenstine says, will likely be a woman.) If members of the human species are driven to scale Mount Everest or slog to the poles, isn't there an inevitable urge onward to Mars and beyond? It's ... you know ... what we do.

"There's a fundamental truth to our nature: Man must explore," Apollo 15 commander David R. Scott radioed in 1971 to ground control in Houston from his spot near Hadley Rille, a valley on the moon. "And this is exploration at its greatest."

There's also the matter of what some futurists call an "insurance policy" for the survival of the species and others call our Plan B in case Earth itself were to become uninhabitable. That could happen through a force beyond our control, like the asteroid that seems to have annihilated the dinosaurs, or by our own folly, through nuclear war or drastic derangement of our climate.

We've been worried about Plan A, and that's a good thing, because it's by far the best plan we have, and it may be the only one. As the environmental activist and author Bill McKibben puts it, the least hospitable patch of Earth is still far more hospitable to human life than any reachable spot we have found anywhere else.

The central irony of the first space age was that the most iconic images it yielded were not those of the moon or the other planets, but the ones of our own planet. "Earthrise," our serene-looking blue orb swaddled in swirling clouds over the moon's horizon, is the most famous. These photographs galvanized the environmental movement, spurred new laws to clean our water and air, and prompted a lot of people to ask a simple question: "Shouldn't we be spending all that money to fix our own problems first?"

The "all that money" part referred to the space program, which in some years consumed 4.5 percent of the federal budget. (Today NASA's budget is half of one percent.) Getting men and women to Mars before now could easily have cost at least that much, so there's a pretty good case to be made that we've been right to take a pass so far.

We're now entering that second space age, in which relentless innovations such as reusable rockets are driving down the cost of getting there. It will surely prove much less expensive to get to Mars in another decade or three than it would be today, and certainly less than it would have been in the 1980s. That's a good bargain, even if those of us who watched Neil Armstrong kick up a little moondust never dreamed that it would take that long.

How much longer remains the wild card.

A serious accident or tragedy in any space venture tends to set back all of them, sometimes by years. Funding is hardly bottomless: For the moment, for instance, plans for asteroid mining seem to have stalled a bit. It may or may not be true that (as the industry's cheerleaders contend) there's a trillion dollars or more to be harvested from rare minerals out in space, but what if it takes $100 billion or $200 billion to develop the technology to try to find out? That's a lot of money to wager that your unicorn will come in.

Finally, space has a dark side, and not just the vast empty blackness that astronauts who have been through it describe. With the United States, China, and Russia all developing space weaponry (for defensive purposes, all three insist), we could find ourselves fighting a future war in space, launching missiles, destroying satellites, and training powerful laser weapons on earthbound targets, including people.

On my way to the Soyuz rocket launch in Kazakhstan, I stopped first in Moscow to meet with a few cosmonauts and visit some museums, because it's hard to

We're entering a second space age, in which innovations such as reusable rockets are driving down the cost of getting to Mars. The wild card: How much longer will it take to get there?

appreciate how NASA's astronauts got to the moon without understanding the challenge posed by the Soviet space program that spurred them there.

Americans tend to view the push to the lunar landing as they would, say, a football game. Nobody really remembers or cares who was ahead during most of the contest; the important thing is who won, even if they had to come from three touchdowns behind to do it. By that score, the U.S. triumphed. End of story.

But in Russia, where Soviet-era cosmonauts are national icons, you come away with a Bizarro World view of a completely different space race.

In the Russian telling, the whole thing was more of a track meet, and they killed on points, even if the Americans bagged a prestige event at the end.

The list of Soviet firsts in space is indeed impressive, from the first satellite, dogs, man, and woman in space to the first multiperson crew and space walk. It's enough to make any American appreciate the magnitude of our national humiliation in space at the hands of our Communist adversaries at the height of the Cold War and why President John F. Kennedy's pledge to land astronauts on the moon and return them to Earth by the end of the 1960s was such a brilliant gambit to recoup prestige on the global stage.

Interestingly, the cosmonauts I met in Russia seemed to share two perspectives with their American counterparts. First, their time in space made them profoundly more interested in protecting the Earth. (Indeed, two cosmonauts gave me books they had written—not on space, but on protecting our environment.) Second, even while strongly favoring human space exploration, they think the idea of permanent, widespread human colonization of space is bonkers.

"It's not … pleasant, actually," Viktor Savinykh said after a long pause when I asked him about living in space.

Savinykh, 79, is famous in Russia for his role in the daring repair of a crippled, ice-encrusted, and dangerously out-of-orbit Salyut space station in 1985. "You get disoriented so easily, you can't remember things up there," he continued. "It's really hard on the brain. All that sun in your eyes. It's hard to describe. Your body weakens."

Still, he acknowledged that Bezos's vision could come to pass someday.

"I don't have the answers to this," Savinykh told me. "The new generation and then the next and then the next—they will get to decide. We did our part."

Those generations are certainly going to ask intriguing questions. Toward the end of the space conference I'd attended in Washington, a panel of U.S. astronauts fielded videotaped queries sent in by schoolkids from around the world.

"Is it possible," a five-year-old boy from Baltimore named Braith Ortenzi wanted to know, "to get from galaxy to galaxy?"

"I'm glad he's thinking big!" replied Chris Ferguson, a veteran of three space shuttle missions who's slated to be on the first Boeing Starliner trip to the space station. "We're going to have to master this whole light-speed thing," he added as the audience broke into laughter, "before we get galaxy to galaxy."

"He'll develop the technology to do it!" interjected Victor Glover, an astronaut slated for the first SpaceX Crew Dragon flight.

"Please take us," said Nicole Stott, a retired astronaut and veteran of two trips to the space station. "Take us with you!"

Glover, nodding with a huge grin, had the final word: "It's on you, brother!" □

Sam Howe Verhovek really did stare long and hard at the moon on July 20, 1969, thinking he might spot the Apollo 11 lunar module. As a boy, **Dan Winters** wanted to be an astronaut; now he revels in chronicling humankind's explorations in space. **Nadia Drake** has dreamed of dancing on the moon for as long as she can remember.

AT THE THE SEA

ONE OF THE MOST REMOTE PLACES ON THE PLANET IS ALSO

AMONG THE MOST ABUNDANT WITH LIFE.

ARGENTINA PLANS TO KEEP IT THAT WAY.

STORY AND PHOTOGRAPHS BY **ENRIC SALA**

END OF THE WORLD

Thousands of juvenile false southern king crabs *(Paralomis granulosa)* swarm a giant kelp forest near Cape Horn, Chile. The species is heavily fished in the region, and such large aggregations are extremely rare.

PREVIOUS PHOTO

Jellyfish float among the fronds of a kelp forest off Isla de los Estados, Argentina. Giant kelps *(Macrocystis pyrifera)* are the largest algae in the ocean, growing upward to more than 150 feet. Their forests harbor one of the most diverse ecosystems on the planet.

Southern sea lions *(Otaria flavescens)* congregate in Francisco Coloane Marine Park in the Chilean fjords. The park also provides refuge for humpback whales to rest and feed as they migrate annually between the Colombian coast and the waters of Patagonia.

Thetis Bay, near the very tip of Tierra del Fuego in Argentina, is about as far south as one can go in the Americas.

Few people ever do. “This is but a bad place for Shipping,” Captain James Cook wrote in his journal in 1768, cautioning future visitors to keep clear of the seaweed. But the bay does provide some shelter from the region’s notoriously rough seas and battering winds. On a chilly, overcast day in February 2018, we launched a Zodiac craft from our ship, the *Hanse Explorer,* and maneuvered it through Thetis toward the shore, careful to avoid the thick blankets of kelp and the sandbanks emerging at low tide.

I was there leading a National Geographic Pristine Seas expedition, in collaboration with the Argentine government, the regional government of Tierra del Fuego, and the Forum for the Conservation of the Patagonian Sea. With me was my old friend and colleague Claudio Campagna, who co-founded the forum in 2004 and

Shooting out of the surf, a southern sea lion bull nabs a southern rockhopper penguin *(Eudyptes chrysocome)* at Isla de los Estados. Southern rockhoppers venture offshore to catch fish, swimming together by the hundreds. There is safety in numbers—for most.

NGM MAPS

has dedicated his life to studying and protecting the marine mammals of Argentina. Our goal was to gather scientific information and produce a film to lay the groundwork for a new protected marine reserve in Argentina's waters.

Creating such reserves—national parks of the sea—is my life's work. Over the past decade, our Pristine Seas team has partnered with local allies to help governments protect more than two million square miles of ocean from fishing and other threats. Our expeditions have taken us diving all over the world, from coral reef islands in the vast Pacific to the frozen archipelagoes of the Arctic.

The expedition to the tip of Tierra del Fuego was especially important to me—not just for what we might be able to achieve but also because of a personal connection to the place. Back in 1973 Paul Dayton, my friend and scientific mentor, conducted groundbreaking research here. Braving polar winds, hail, and snow, and wearing only old-fashioned wet suits—as opposed to our modern dry suits—Paul and his buddies dived around Thetis Bay and Isla de los Estados (Staten Island) just to the east. They measured and counted giant kelps and the invertebrates living under the kelp forest canopies fringing the shores. Nobody had studied these underwater habitats, and part of our mission was to redo Paul's surveys. I've seen firsthand the dramatic changes in other parts of our oceans caused by overfishing and climate change, the most conspicuous being

This article was supported by Pristine Seas donors and the Wyss Campaign for Nature, which is working with the National Geographic Society and others across the globe to help protect 30 percent of our planet by 2030.

I've seen the dramatic changes in our oceans caused by climate change: the death of coral reefs and the shrinking of Arctic sea ice. What would we find here beneath the surface?

A large southern red octopus *(Enteroctopus megalocyathus)* rests on a bed of sea urchins at Isla de los Estados. Sea urchins are voracious kelp feeders, capable of denuding entire forests—but here the forests still thrive. Octopuses eat fish and crabs, dead and alive.

Giant kelps continue to grow once they reach the surface, creating a canopy through which sunlight filters as if through the stained glass of a cathedral.

Krill swarm inside a giant kelp forest at Islas Diego Ramírez, 60 nautical miles southwest of Cape Horn. Krill form the base of an enormous food web, supporting fish, penguins, sea lions, fur seals, whales, and—atop the web—orcas, among the ocean's most formidable predators.

the bleaching and death of coral reefs and the shrinking of Arctic sea ice during summer. What were we going to find here beneath the surface, 45 years after Paul's visit?

A petrel flies over a colony of southern rockhopper penguins at Isla de los Estados. More than 10 percent of the world's population of this vulnerable penguin species lives here.

CLAUDIO AND I STEPPED on the beach and immediately realized we were walking on a mass grave. Old sea lion bones crunched underfoot with every step—the legacy of hunters in the first half of the 20th century. Some skulls had holes made by metal picks. There were jaws and teeth from huge old males and little juveniles. Sea lions and fur seals had been taken indiscriminately, mainly for pelts and for blubber to boil for oil.

By Paul Dayton's time, the Argentine government had protected these species by law, but they have yet to recover. According to researchers, local sea lion numbers are a fifth of what they were more than 70 years ago, possibly because of the dramatic decline of reproductive females and the vast footprint of industrial fishing.

"In the past, people killed them directly," Claudio said. "Now we're depriving them of their food too." Three days before our visit to Thetis Bay we'd seen a 360-foot-long supertrawler at the port of Ushuaia. Its nets were big enough to hold a dozen Boeing 747s. Such bottom trawlers and long-liners operate at the edge of the continental shelf of Tierra del Fuego, where the deep basin begins.

Nearer to shore, the weather is so brutal most of the year that few go through the effort to dive at Thetis Bay and Isla de los Estados, but having arrived in relative calm, we were able to dive around the island for two weeks.

The cold, nutrient-rich waters feed giant kelp forests that harbor one of the most magnificent marine ecosystems on the planet. Pillars reach from as deep as 150 feet to the surface, sometimes adding a foot and a half in a day. Giant kelps continue to grow once they reach the surface, creating a canopy through which sunlight filters as if through the stained glass of a cathedral.

Paul had graciously scanned and copied his handwritten notebooks for us; the pages were filled with detailed natural history observations from 1973. We carried them like treasure. Giant kelp forests all look the same from the surface, but underwater it's a different story.

Paul had found that every little bay had its peculiarities, sort of an ecological personality. In one bay the kelps were covered only by one or two species of clams; in another, by little soft corals; and in a third, by baby sea cucumbers with finely branched plumes for capturing food particles in the rich seawater.

To our astonishment, the kelps in each bay still harbored the same species. The oceanographic conditions appeared to have remained similar here for the past half century: Climate change had made no permanent mark yet. This seemed a wonderful gift, and I felt a burst of joy.

We were amazed as well by the abundance of life. Every square inch of the bottom was occupied by a living organism: white and yellow sponges, pink encrusting algae, lollipop-like sea squirts. Giant kelps bent to the seafloor from the weight of the mussels growing on them. Blue starfish gorged on the mussels, along with snails and hermit crabs. A year before, on the Chilean side of this ocean ecosystem not far from Cape Horn, we'd stumbled upon a massive aggregation of another crab species, called false southern king crabs. Two layers of them covered the bottom while many more climbed the giant kelps and parachuted down on their fellow crustaceans—and on our heads. It was as if we were part of a Japanese science fiction film. Crabzilla!

ONE DAY WE TOOK A BREAK from the diving and ventured to the basin beyond the edge of the continental shelf. The Yaganes Basin is the heart of a massive, connected ocean ecosystem that ranges across the southern tip of Chile and Argentina to Antarctica, in a convergence of Pacific, Atlantic, and Antarctic waters. Our engineer, Brad Henning, had brought along several National Geographic Dropcams, glass (borosilicate) spheres enclosing cinema-grade cameras and lights. They have a weight system that carries the camera to the bottom, then returns it to the surface hours later—perhaps with a trove of never seen before footage of the seafloor.

The Dropcams did not disappoint. When Brad showed us a selection of video clips the cameras had captured, our jaws dropped. Toothfish, hake, and other deep-sea fishes flocked to the bait Brad had attached to the Dropcam. At one point a fat red squid approached the camera, then vanished in an explosion of ink. Many of these species are overexploited in the basin. To

see them still there means their populations can rebound, if humans let them.

After the expedition we changed from wet suit to business suit to lobby Argentine government officials for ocean protection along with our partners at the Forum for Conservation of the Patagonian Sea and Tompkins Conservation. Alex Muñoz, Pristine Seas director for Latin America, presented the results of our expedition to the government, in support of a plan to create the Yaganes marine park. We also premiered our documentary film from the expedition in Buenos Aires, bringing the marine wonders of Yaganes and Tierra del Fuego to Argentine leaders and citizens.

In December the Argentine Parliament convened an extraordinary session to consider the proposal. We were all nervous. We knew that the National Park Administration and some key leaders in government supported protection of the area. But under Argentine law, the bill to authorize the park had to be approved by the House of Representatives and the Senate.

After some tense negotiations, the House voted on December 5. I was astonished. The bill passed on a vote of 196 to zero—as resounding an affirmation for conservation as I've ever witnessed in any country. The Senate gave it the final blessing on December 12. Chile had already designated its own fully protected marine park south of Cape Horn a year earlier. Forty years ago Chile and Argentina had come to the brink of war over disputed territorial rights south of Tierra del Fuego. Now the presidents of the two countries would like to declare the area a marine peace park—possibly the largest contiguous transboundary protected oceanic area.

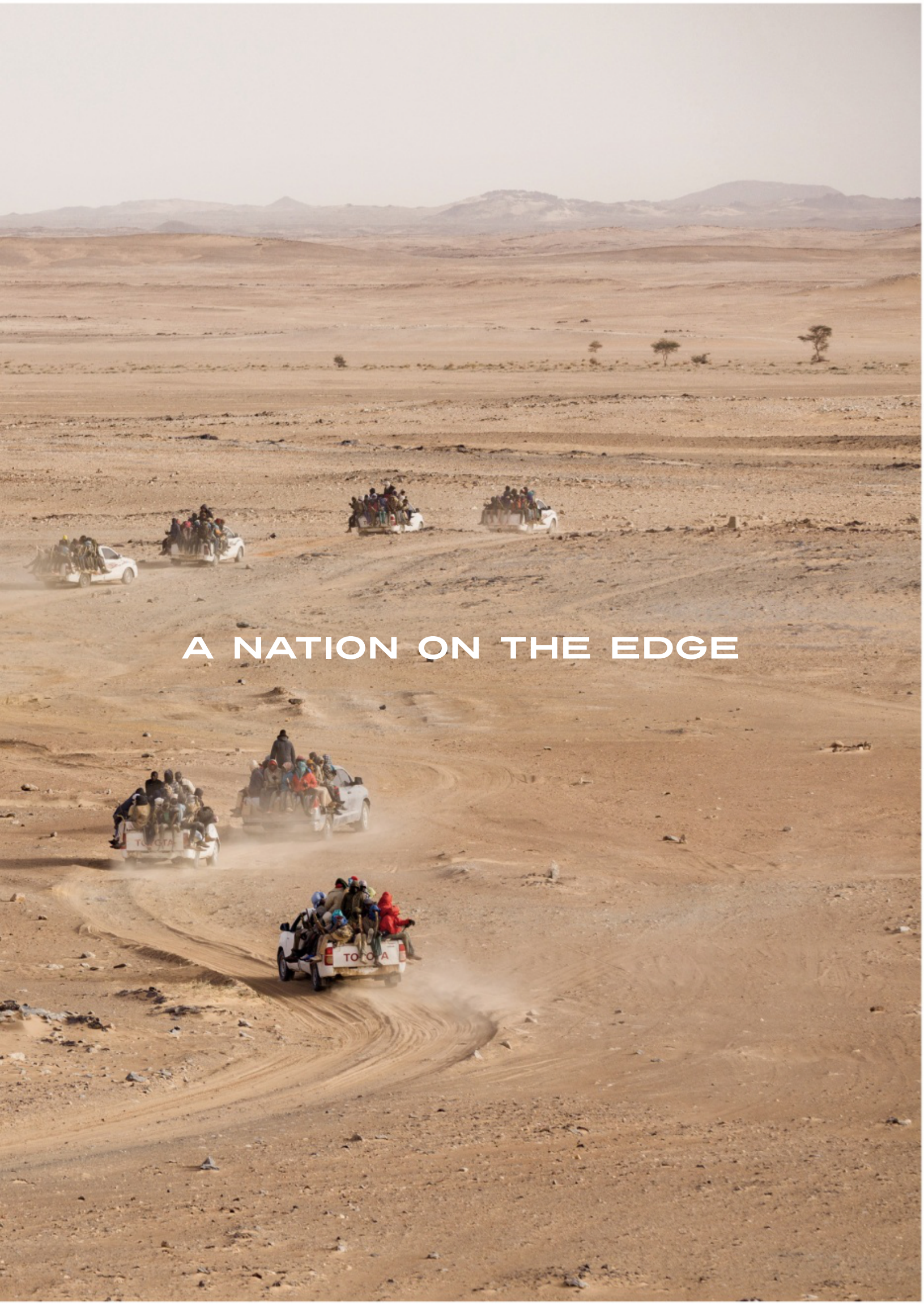
"Today is a day of joy for all Argentines," Claudio told me on the phone, after the park bill was signed into law. But the joy isn't only for Argentines. Having had the privilege of exploring and documenting these waters, I feel that the ocean has won a little bit back against our relentless quest to empty it of life. Thanks to the leadership of two governments, the integrity of the great ecosystem of the sea at the end of the world will be maintained for years to come. □

National Geographic Explorer-in-Residence **Enric Sala** is the founding director of Pristine Seas, which—with government leaders, NGOs, and local communities—has helped protect more than two million square miles where ocean life can thrive.

IN THE MIDDLE OF ONE OF THE WORLD'S ROUGHEST NEIGHBORHOODS, NIGER CLINGS TO STABILITY. BUT FOR HOW LONG?

BY ROBERT DRAPER
PHOTOGRAPHS BY
PASCAL MAITRE

A NATION ON THE EDGE



Young men from Niger and elsewhere wait in a migrant "ghetto" in Agadez, Niger, for a caravan to Libya. With low life expectancy, limited educational opportunities, and a high poverty rate, Niger ranks at the bottom of the UN's Human Development Index.

PREVIOUS PHOTO

A convoy of pickups packed with Nigeriens and other Africans begins a three-day trek from Agadez through the Sahara to Libya. Many migrants intend to work there; others hope to reach Europe.

A truckload of clothes, furniture, appliances, and various other household items arrives at customs in Agadez. Nigeriens working in Libya send earnings home as goods, not cash, because the Libyan dinar is unstable.

JUST BEFORE DUSK,

THE FIRST PICKUP

TRUCKS ROLL PAST

THE CHECKPOINT

AND ARRAY THEMSELVES

ACROSS THE DESERT

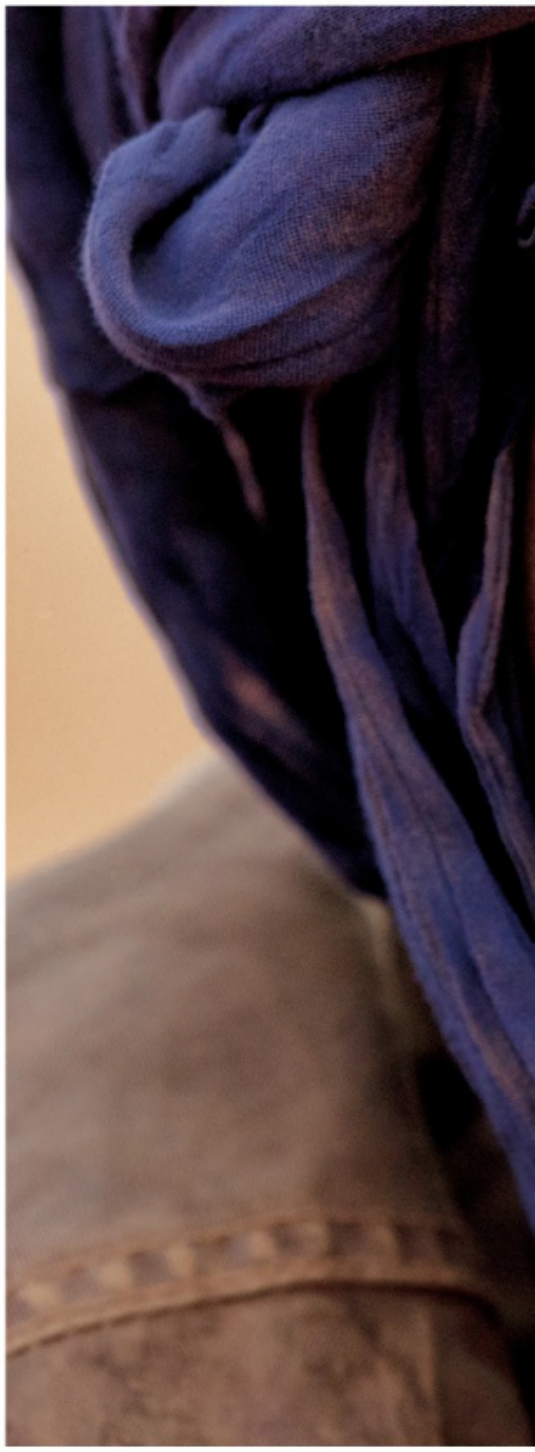
ON THE OUTSKIRTS

OF AGADEZ, NIGER.

Passengers pile in, as many as 25 per vehicle, each carrying no more than a knapsack. They wear sunglasses and scarves to fend off the sand, along with heavy coats for the biting-cold nights on the three-day journey to Libya.

Their youth is palpable. Squeezed together among strangers, they fidget and stare listlessly at the empty landscape awaiting them. Vendors with rusty pushcarts hawk thirdhand coats, sugarcane, plastic bags of water, cigarettes, and wooden poles to use as braces against the possibility of falling out and becoming stranded in the lawless, desolate Sahara as the unpitying motorcade recedes.

Trucks keep arriving. More than a hundred will assemble by the time the procession begins. Two military vehicles lumber forth—one to lead, the other to guard the rear. As night falls, a swarm of motorcycles materializes and surges past the city's checkpoint, ferrying a frantic, last-minute wave of aspiring travelers who wish to negotiate their way into the overstuffed pickups. Amid the swirling sand and the pell-mell assimilation of the stragglers, one motorcycle skids to a halt. Even seated, the rider is a



A teenager is dusted with sand from toiling in a mine. He is one of many Nigeriens who joined the rush for gold in the north, the last hope for jobless men after tourism plunged, uranium mining declined, and a law made transporting migrants a crime.

large, imposing figure. With an undomesticated beard and a toothpick wedged between his lips, he considers the melee with an incongruously beatific smile.

Then he cackles: "Rice and beans!"

The Boss—which is what everyone in Agadez calls the man—is not describing food. He refers, instead, to the composition of the convoy. You have rice: the many hundreds of Nigerien passengers who have joined this weekly caravan to Libya to find work. Then you have others, the beans—no more than maybe seven per pickup—who are from elsewhere, and who are headed elsewhere, for reasons of their own. It is the Boss's recipe. He is, you could say, an exporter of beans. Countless thousands of them, since he first entered the business in 2001 and continuing even after Niger's government made it illegal in 2015.

The flow of travelers has not stopped, and it will not stop. West Africa's intensifying instability guarantees this. The Boss's job is to manage the flow. As a *passeur,* he sits at the top of a shadowy network, possibly the biggest in Agadez, consisting of at least a hundred drivers and about as many *coxeurs,* subordinates who handle the arrangements. Before the trucks arrive at the checkpoint, they obtain their authorization papers at the Agadez bus station from a city official, who happens to be the Boss. Payments are made. Papers signed. Eyes averted. The journey begins.

"They know me everywhere," he declares.

PRECARIOUS CROSSROADS

The arid expanses of Niger have been a nexus of trade and transit for centuries. Impoverished but relatively stable, the country is surrounded by conflict zones where Islamist terrorist groups have taken root. Western, UN, and regional military forces all increasingly see Niger as a crucial base for combating extremism in the region.

Northbound migrant routes Major Other

Number of terrorist attacks, 2001–2018

51 or more
10-50
6-9
2-5
1

Boko Haram
Groups linked to Islamic State or al Qaeda
Other Islamist groups

Mining areas in Niger

Gold Uranium

Foreign military presence Base, outpost, or other installation

United States France Germany Italy United Nations

0 mi 100
0 km 100

DANGEROUS MIGRATION

Nearly nine of 10 migrants in northern Africa are on the move to seek better economic opportunities. They follow well-worn routes through lands where the governments are weak and terrorist groups are thriving.

EUROPE
ASIA
AFRICA
MOROCCO
TUNISIA
ALGERIA
LIBYA
EGYPT
MAURITANIA
MALI
NIGER
CHAD
SUDAN
ERITREA
NIGERIA
CAMEROON
CEN. AF. REP.
SOUTH SUDAN
ETHIOPIA
SOMALIA
KENYA
UGANDA
DEM. REP. OF THE CONGO
Tripoli
Cairo
Bamako
Niamey
AGADEZ
Khartoum
Addis Ababa
Mogadishu

AREA ENLARGED

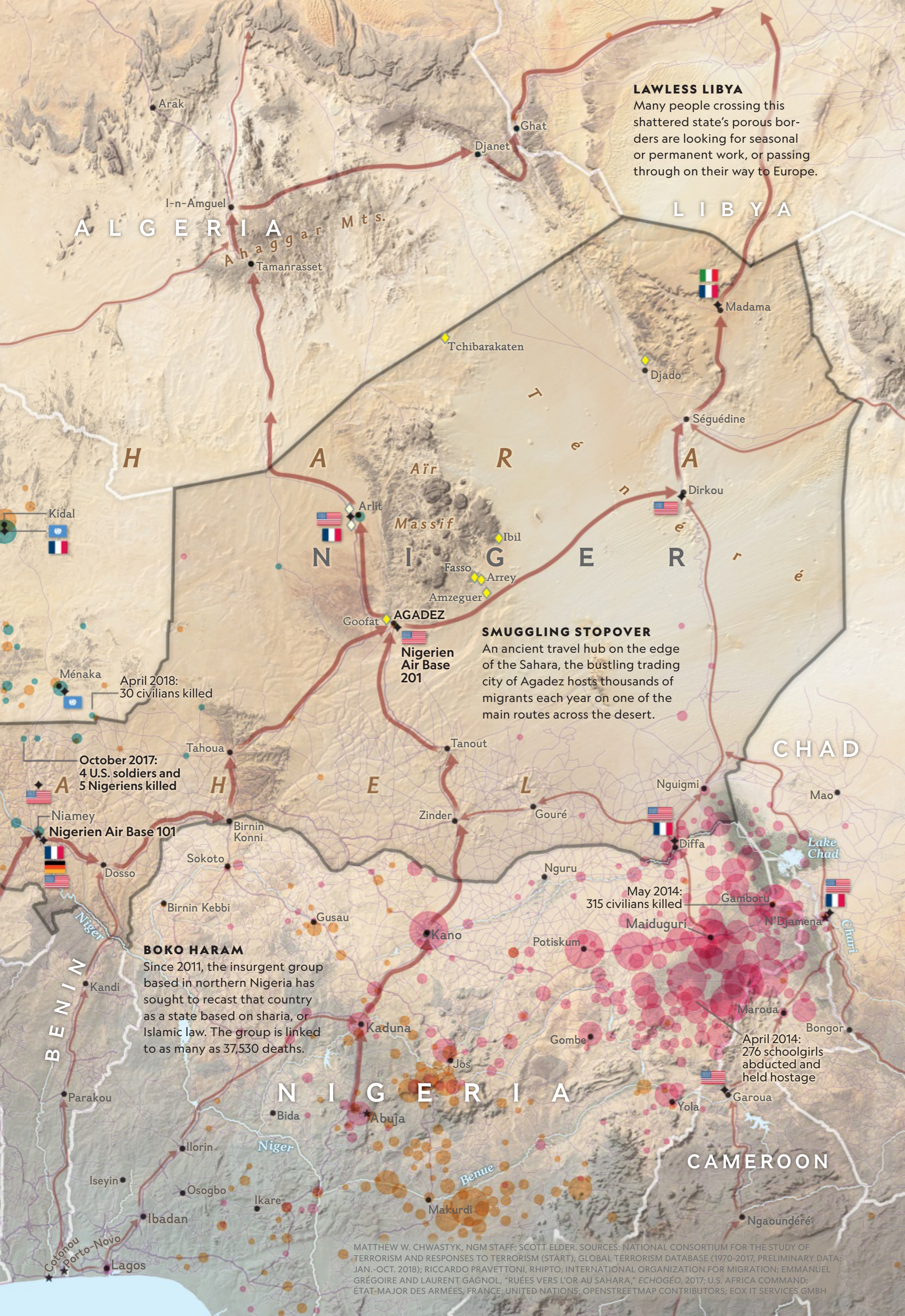
Islamist terrorist activity
Less More

Taoudenni
El Djouf

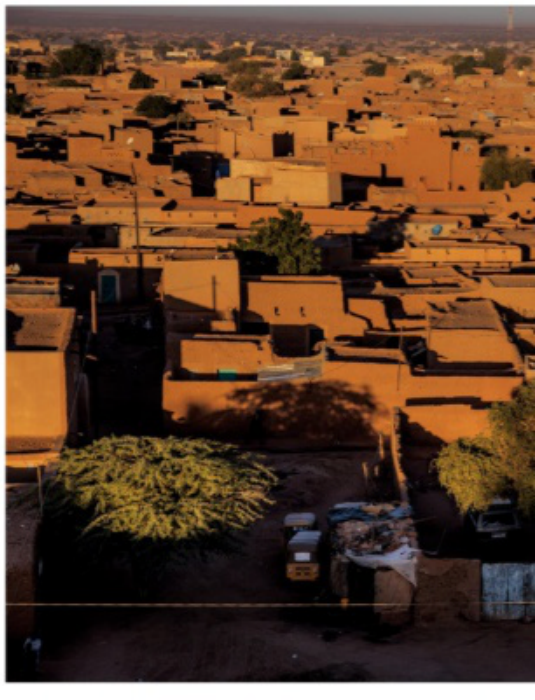
TERROR IN THE SAHEL

Thousands of UN and French troops are deployed in Mali to maintain regional stability. Yet groups linked to the Islamic State and al Qaeda regularly attack both military and civilian targets.

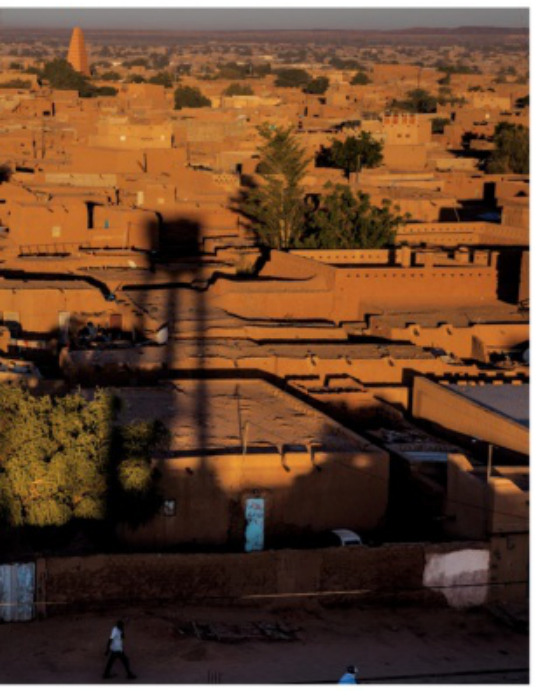
Bordj Badji Mokhtar
Tessalit
Aguelhok
Araouane
MALI
Timbuktu
Ber
Bourem
Niger
Goundam
Gao
Ansongo
January 2018: 14 Malian soldiers killed
Douentza
Mopti
Niger
Gorom-Gorom
Ayorou
San
Ouahigouya
December 2016: 12 Burkinabe soldiers killed
BURKINA FASO
Ouagadougou
Koupéla
August 2017: 21 killed in restaurant attack
Bobo-Dioulasso
Sansanné-Mango
TOGO
Tamale
CÔTE D'IVOIRE (IVORY COAST)
Blitta
GHANA
Lake Volta
Kumasi
Lomé



MATTHEW W. CHWASTYK, NGM STAFF; SCOTT ELDER. SOURCES: NATIONAL CONSORTIUM FOR THE STUDY OF TERRORISM AND RESPONSES TO TERRORISM (START), GLOBAL TERRORISM DATABASE (1970-2017, PRELIMINARY DATA: JAN.-OCT. 2018); RICCARDO PRAVETTONI, RHIPTO; INTERNATIONAL ORGANIZATION FOR MIGRATION; EMMANUEL GRÉGOIRE AND LAURENT GAGNOL, "RUÉES VERS L'OR AU SAHARA," *ECHOGÉO*, 2017; U.S. AFRICA COMMAND; ÉTAT-MAJOR DES ARMÉES, FRANCE; UNITED NATIONS; OPENSTREETMAP CONTRIBUTORS; EOX IT SERVICES GMBH



Agadez has long been a crossroads of trade, connecting the Sahel to North Africa and West Africa to the Middle East. The city's bus station (top) is the hub for migrants, while the livestock market (bottom left)



caters to a mainstay of the area's economy. The historic city center (bottom middle) is built of mud brick and dates to the 15th and 16th centuries. Two Tuareg women socialize in a hookah bar (bottom right).

"Even on the internet, you find pictures of the Boss with immigrants." He facilitates their trans-Saharan passage from Agadez to the central Libyan city of Sabha. Then he enlists a counterpart to guide them from Sabha to Tripoli, and another to ferry them across the Mediterranean to the West. Where the travelers ultimately wind up—in Italy, in the United States, in a deportation cell, or left to die in the desert or to drown in the sea—is outside the Boss's purview.

Still, something deeper than a trickster's boast is evident when he proudly recalls a client who made her way from Cameroon to Agadez to Germany in less than two weeks. A criminal to some, the Boss, who owing to the shadiness of his enterprise does not divulge his name, would prefer to think of himself as a highly entrepreneurial public servant.

THE BOSS IS, ABOVE ALL, a stabilizer in a region with few such actors. To the uninitiated, the tableau at the checkpoint looks out of control. But it is not. A system is at work—one that is understood by all and benefits many. Being illegal, it is not the best system. But it is a creative solution to an unavoidable fact, which is that Niger is surrounded by chaos. Though it is a country of myriad woes—deep poverty, rising population, a shortage of arable land made worse by desertification, and a shaky political system—it is not the incubator of violence that its neighbors are. It is a country people flee through, not flee from. Niger's fate depends on whether it holds off the chaos and maintains a semblance of order, or succumbs to it altogether.

The Boss's role in Niger's drama of brinkmanship did not become apparent to me until one Sunday morning, when he and I spent several hours driving together through the migrant "ghettos" of Agadez. It is an ancient, low-slung city with a sultan's palace and a 500-year-old mosque at its historic center, the outlying neighborhoods composed largely of mud and straw, with more than 130,000 inhabitants, not counting the Boss's many clients just passing through.

We found some of the latter behind mud-brick walls, killing time quietly in back rooms, waiting for the Monday convoy. Four boys, 15 to 18, from Burkina Faso, Mali, and Ivory Coast, eyes glassily attuned to a small TV. A wiry 50-year-old man from Cameroon hoping to rejoin his wife in Germany but for now pacing in an unlit room with walls covered in graffiti from others in transit: *Ezekiel. Tala. Cherif Kante. May God help us all.* Two brothers from a Burkina Faso village, skinny but with impeccable teeth, impeccably innocent: had not gone to school, did not know their ages, had a brother waiting in Algeria, had only a change or two of clothes, hoping somehow to get to a place called Europe.

That same morning, the day before the convoy was to head out, the Boss escorted me behind a wall and into a courtyard littered with rusted car parts, where a couple dozen young African men—most but not all from Niger—were sleeping or smoking in the shade. An 18-year-old from Agadez named Mohammed was tinkering with the engine of his pickup. He had returned from Libya with the convoy just two hours earlier and was visibly groggy. Tomorrow he would be northbound again. Mohammed said that he had been traveling this circuit every week since he was 15. Bullet holes scarred the passenger seat and left-rear fender of his battered truck. He had been held up in the desert four times in the past three years. Mohammed assured me that such experiences had scared the hell out of him. He had been an auto mechanic and still did repair work, he said, but added, "The money is better here."

The teenage truck driver, his fidgety passengers, even the Boss: In the end, their stories converge. Unrest is the abiding narrative of West Africa. It is a region thrashed by economic despair, spiking and drastically shifting population, environmental degradation, political instability, and, increasingly, violence. It is spinning out of control. And Niger, haloed as it is by five of the continent's greatest incubators of Islamist extremist groups—Algeria and Libya to the north, Mali to the west, Chad to the east, and Nigeria to the south—is poorer than all of them and yet the most pacific, for now. As the U.S. ambassador to the country, Eric Whitaker, gently puts it, "Niger is a good country in a rough neighborhood."

Preserving its safe distance from peril is a vexing proposition. But given the country's status as "a critical actor in regional efforts to counter terrorism and promote stability" (as the State Department puts it), a tacit understanding among some Western powers seems to have coalesced: Lose Niger—the one country in its "rough neighborhood" that has not become a cauldron of violence and extremist activity—and all bets are off. It is why an air base was being built by the U.S. Air Force on the outskirts

of Agadez when I was there and why U.S. special operations forces have participated in counterterrorism missions in Niger—one of which in October 2017 led to the deaths of four U.S. soldiers, four Nigerien soldiers, and a Nigerien interpreter in an ambush by Islamist militants. It is why foreign aid makes up 40 percent of Niger's budget. It is also why the Boss, while dispersing West Africans across the globe, is in his own paradoxical way helping to hold a region together that could very easily come apart.

One morning the Boss paid a visit to my hotel in Agadez. He slouched in a chair on the patio, wearing sunglasses and a turban, a toothpick in his mouth, brooding as he listened to a French radio program on his smartphone. Eventually he muttered, "The European community has blocked everything. Tourism, migration, the mines. What else is there to do but sleep? Someone bites you and then tells you not to cry."

THOUGH NIGER IS A COUNTRY OF MYRIAD WOES—

POVERTY, DESERTIFICATION, A SHAKY POLITICAL SYSTEM—

IT IS NOT AN INCUBATOR OF VIOLENCE.

IT IS A COUNTRY PEOPLE FLEE THROUGH, NOT FLEE FROM.

THE VILLAGERS OF GOOFAT, an hour's drive from Agadez, gathered one day last December. Mostly Tuaregs, a semi-settled, largely Muslim group, they were electing a chief for the first time. The event was one of scrupulous fanfare. A cow was slaughtered, and a band played folk songs. The women wore gold jewelry with their faces tinted yellow as they sat cross-legged on rugs. The men wore bright turbans and their best robes. One by one, a representative from each of the village's 270 or so families—often a woman—was called by last name to fill out a ballot for or against the sole candidate and drop it into a plastic bin.

After nearly two hours of voting and ballot counting, the landslide winner, a slender, middle-aged man from the Kourouza family, dutifully stepped forward, took his place in a chair, and affected a regal scowl while village elders solemnly wrapped his head in a purple turban.

Beneath the pageantry, however, lurked a disquieting reality: The families elected Mohamed Kourouza chief because they had decided Goofat had grown too big to remain ungoverned. Infants and small children far outnumbered the adults in their dazzling wardrobes. The agrarian village's population, about 2,300, has roughly doubled in less than 20 years. With more babies comes the need for more schools, more social services, and more grazing land, along with the potential for more conflict. Writ small, Goofat is the cautionary parable of Niger—a country nearly twice the size of Texas, with about three and a half times its fertility rate but a mere 0.5 percent of its gross domestic product.

Even by a troubled continent's standards, Niger's predicament is grave, bracketed by two sobering statistics: a GDP per capita of about a thousand dollars, one of the world's lowest, and a fertility rate of seven births per woman, which is the highest. But demography does not fully explain the precarious state of Niger. As a landlocked desert country, it has faced punishing droughts, and climate change is expected to make them harsher. Poverty and environmental fragility have in turn exacerbated political instability.

Since gaining independence from France in 1960, Niger has endured four military coups, the latest in 2010. In the past 30 years, it has also experienced two bloody Tuareg rebellions. The most recent, which ended a decade ago, left an abiding scar across the largest of Niger's eight regions, Agadez. Until then, the city of Agadez had been a tourist gateway to the Sahara, receiving up to 20,000 visitors annually, many via direct flights from Paris. The three years of violent skirmishes between the rebels and Niger's army had the effect of vaporizing the predominant industry. The travel business began to regard Agadez as a *zone rouge*.

Into the void stepped the Boss and others in the migrant-moving trade. Because of the city's geographic position, Agadez—derived from the Tuareg word *egdez,* "to visit"—had for centuries been a transit point for salt caravans and other camel-borne nomadic traders. As a hub for African migrants, Agadez was well situated and, for that matter, well equipped with former tourist guides and drivers.

"As many as 300,000 migrants came through

Hundreds of shafts line a gold mine in northern Niger on the border with Algeria. Teams turn cranks to lower miners more than 300 feet to gold-bearing layers. The miners bring up rock to be crushed, releasing the treasure.

Buyers choose animals at the livestock market and send them to this slaughterhouse in Agadez, where camels, goats, sheep, and other animals are killed and then sent to butchers who sell the meat.

here every year," recalled the city's mayor, Rhissa Feltou. "Drivers, hotels, markets, banks, telephone companies—the whole city benefited."

The migrant flow became a gusher in 2011, after the fall of Libya's ruler, Muammar Qaddafi, ruptured Niger's border with Libya. But the southbound traffic now included guns diverted from Libyan government stockpiles. The barely checked acceleration of migrants further strained social resources in European countries while creating humanitarian tragedies in the desert and at sea. The porousness of African borders raised concerns about the spread of terrorism—all the more so since the U.S.-led efforts in Afghanistan against al Qaeda and in Iraq against ISIS had compelled those groups to seek a more hospitable refuge.

After the European Union offered financial inducements, Niger's government in 2015 criminalized transporting migrants. In Agadez the police confiscated scores of pickup trucks. Coxeurs and drivers were arrested, along with the Boss, who spent three weeks in jail. The city's number one source of revenue had been officially banned, in effect consigning Agadez's post-tourism economy to the black market.

Even with the crackdown on human smuggling, Agadez's location ensures it will remain a transit point for foreign travelers. Today it has a new type of guest. Known as Air Base 201, it is a military installation owned by the Nigerien government but leased by the U.S. and inhabited by some 550 of the latter's Air Force personnel. Its existence is hardly a secret, but its American occupants are a discreet presence—showing up in Agadez to rebuild a school, or in a nearby village to construct a water well, but largely staying on base. When I visited in December, American military engineers were busily constructing a mile-long runway that can withstand desert conditions. C-17 and C-130 aircraft will use the runway, along with weaponized MQ-9 drones, which will not only monitor the activities of extremist groups but also target them.

These operations will extend well beyond the Agadez region and into the "rough neighborhood" that has bred extremist groups. "The enemy exploits these borders—which are very porous—all the time," said Samantha Reho, spokeswoman for the U.S. Africa Command, responsible for overseeing the U.S. military's role in Niger.

The counterterrorism mission comes with obvious risks, attested to by the October 2017 ambush. (No incidents of U.S. troops drawing fire have been reported in the past year.) But the American military presence is an act of national security self-interest, not foreign benevolence. As the State Department starkly describes it, "U.S. foreign assistance to Niger plays a critical role in preserving stability in a country vulnerable to political volatility, terrorism and the spread of violent extremism, food insecurity, and regional instability."

Agadez itself has not been named in recent intelligence threat assessments, according to a U.S. defense official. But the presence of a military base and the city's distance from the borderlands can protect Agadez for only so long. The conversations behind mud-brick walls reflect a gathering discontent. Young men enumerating their all but exhausted options. They had attended school, looked for work, played by the rules. With few jobs to be had, some found their place in the Boss's racket. After seeing friends get arrested and their trucks impounded, they withdrew. And now they are waiting for whatever might come next.

Meanwhile they were hearing about other young men making appeals: Looking for a job? We will pay. Need money for a wedding? We will pay. The YouTube videos and WhatsApp texts from the Nigerian jihadist group Boko Haram were making the rounds.

One evening at a *fada*—an ad hoc social gathering of young Nigerien men over hot tea and card games—an enterprising individual who had once made a decent living importing pickups but now had few takers bowed out of the crazy eights game and considered his lot morosely.

"Things cannot keep going at this rate," he said quietly. "It will become a jungle."

AT THE SOUTHERN EDGE of the Sahara, a West African gold rush is under way. Thousands of men attack a rubble-strewn scrubland. Some swing pickaxes and use shovels. A few operate a power drill. Others have no tools at all—only rocks to loosen the dirt by hand.

Occasionally the ground shakes, accompanied by a muffled concussive boom: dynamite. It's a more efficient way of digging, if rather dangerous and for that matter illegal—though many if not most of these men already are going about their work without an official government permit.

All around them stretches what one might call

a tent city, except that the tents have been tattered by the winds into ribbons that flap above miners who lie snoring on the ground.

The squatter village is called Amzeguer, and it did not exist until about five years ago.

In a drearily familiar African paradox, Niger is mineral rich, the world's fifth largest producer of uranium, even as it ranks lowest on the United Nations' Human Development Index. (Its three largest mines are joint ventures with French multinationals. The plummeting price of uranium has led to layoffs of Nigerien workers.)

A YOUNG MAN WHO HAD ONCE IMPORTED PICKUPS NOW HAD FEW TAKERS.

'THINGS CANNOT KEEP GOING AT THIS RATE. IT WILL BECOME A JUNGLE.'

In 2017 the government closed its largest gold-mining area, on the Djado Plateau to the north—ostensibly because of terrorist activity, though more likely because of foreign miners coming in from Chad, Sudan, and Libya. Many of the Nigerien miners were now here, along with other men from Agadez whose labors constituted a desperate stab at a quasi-legitimate livelihood.

"Do I have hope?" says a 46-year-old man named Jamal, who then pulls his scarf away to reveal his sand-caked face. "Look at my beard. It's turning white from hoping."

Jamal stands on a hill pocked with deep holes. "We dug down to 53 meters deep, but then we hit water," he says. "We need to flush it out. There's a pump all of us share, but it broke down." He points several yards away, to a lanky miner in a blue jumpsuit almost entirely coated with a film of dust. The man, along with his 11 sons (ages 12 to 30), had managed to dig a hole to 60 meters and had encountered traces of the precious mineral. "The gold's right there waiting," Jamal maintains. "We just need to find some money to fix our pump."

Amzeguer has been Jamal's workplace for nearly three years. Before that he was a desert guide for migrants based in Agadez, with six drivers under his supervision. After the migration ban took effect, the police seized two of his pickups. Now he is a penniless artisanal miner. Several of his new colleagues died in the shafts after a tool was dropped on them or a mine collapsed. "Both jobs are risky," he says.

"But," he muses, "if someone calls me from the city, saying, 'I've got 50 migrants, and can you help move them?' of course I'll do it." Jamal's voice is matter-of-fact. "If I can't find gold, I'll go back," he says. "If not on a Hilux truck, then on a camel caravan, the way they used to."

"UNTIL VERY RECENTLY, you did not find thieves in Agadez," said Sheikh Salahadine Madani, the imam of Agadez's strict Islamic school, Daroul Kouran. "They would work in tourism or with migrants or go to the mines to find gold. Now, when I visit the prison, I see people I would never expect to see there. They are honest people who became desperate."

The imam, visiting my hotel, sipped a Coca-Cola under the shade of a patio umbrella. His voice was heavy with lament. Nonetheless, he bristled when I mentioned to him that the orthodox Islamic movement he's part of, known as Izala, has historical ties to Boko Haram's founder.

"The Quran doesn't say that you should kill innocents in the name of Islam," he pointed out. Madani conceded, however, that the path from economic desperation to violent extremism was well worn. "Yes, I've seen this," he said. "You hear kids sometimes talking about how they have no opportunities. You hear them in the streets talking about how maybe this is the only option left."

Still, this option—calamitously antisocial, blasphemous, ultimately self-nullifying—seems anathema to West Africans, who go to astounding lengths to avoid it. Whatever one may think of the Boss and his clients, their sheer tenacity is astounding.

One morning at a shelter in Agadez that helps migrants return to their homelands, I met Mohamed, a 19-year-old from Ivory Coast who wore a necklace with a razor blade dangling from it. Mohamed had been there for five days.

He said, without going into specifics, that there had been family problems back in his village—and that, regardless, his dream had

In Agadez, an Izala school educates about 1,300 students. Izala is a back-to-basics Islamic reformist movement that adheres to conservative practices, such as women covering their faces, but also prizes education.

A Tuareg woman in Goofat casts her family's vote in the election of a village chief. Within the past 20 years, the village population has doubled to 2,300, paralleling a nationwide demographic trend.

always been to live in America. And so, in August 2018, Mohamed paid for a six-day drive in the back of a pickup to Gao, in Mali. Along the way, he and the 19 other passengers were robbed and several of their water bottles slashed by bandits. They walked the final 70 miles in the desert to Algeria.

Mohamed spent a month working as an auto mechanic in the border town of Bordj Badji Mokhtar. He then traveled by foot and hitched rides into Morocco, hoping to find passage by water to Spain and from there to the U.S.

Instead Moroccan immigration authorities jailed him for five days. He then escaped back to Algeria, where he was briefly jailed again before being relieved of the last of his money. Finding no further use for him, Algerian authorities deposited Mohamed onto the back of a dump truck, which drove him into Niger and left him in the desert. After several days on foot, he arrived in Agadez, four months from the beginning of his fruitless journey.

When the mechanic had finished telling me his story, he did not seem particularly discouraged by it. Before I could offer any sympathy, he blurted out, "I don't want to go home. I've decided on my goal."

Mohamed had a new plan. He would return to Ivory Coast, make money, get a passport, and buy a direct flight to Morocco, bypassing the desert altogether. And then to the sea.

"If God gives me the chance," he said, "and I arrive in Europe alive and healthy, I think I can make it"—by which he meant make it to America, a land of millions of vehicles in need of a clever mechanic. ▯

Robert Draper has reported from a dozen African countries as a contributing writer. **Pascal Maitre,** a frequent contributor to *National Geographic,* has visited Niger 15 times on assignment.

A U.S. Air Force crew paves a runway at a new Nigerien air base near Agadez that will deploy weaponized drones. Hundreds of U.S. airmen stationed at the outpost will assist in the regional fight against terrorist groups, including affiliates of ISIS and al Qaeda.

Why did a U.S. mission in Niger turn deadly?

A NEW DOCUMENTARY QUESTIONS THE PENTAGON'S ANSWER, WHICH PLACED BLAME ON A SPECIAL OPERATIONS TEAM.

BY THE ABC NEWS INVESTIGATIVE UNIT

Debra Gannon's son, Sgt. 1st Class Jeremiah Johnson, was one of four U.S. special operations soldiers killed in Niger on October 4, 2017, when Islamist fighters ambushed their team. The clash near Tongo Tongo was the deadliest for U.S. forces in Africa since the "Black Hawk Down" battle in Mogadishu, Somalia, 24 years earlier. The foggy circumstances of the gunfight—the subject of much debate—have confused the families of the fallen, and the public.

Gannon believes her son, along with Staff Sgt. Bryan Black, Staff Sgt. Dustin Wright, and Sgt. LaDavid Johnson, fought heroically. But in an investigation into what went wrong, the military laid much of the blame on the team rather than its senior commanders. The Marine Corps general overseeing U.S. military operations in Africa praised special operations units for "serving well," but pointed out, "This particular team is not indicative of what they do."

The military's conclusions stung the families of the deceased soldiers and contradicted what they were hearing from other team members and news reports. "That really infuriated me," Gannon says. "They're trying to make them look bad."

Gannon's son was part of a 10-man team training, advising, and working with 34 Nigerien soldiers. As they returned to base after searching a campsite recently used by an Islamic State affiliate leader, they were attacked by more than a hundred extremists.

In a yearlong investigation, ABC News learned from multiple sources that the Pentagon, in briefings for the grieving families, withheld information about the crucial decisions that put their sons in harm's way. Most significantly, sources inside and outside the armed forces told ABC that the team's captain had strenuously objected to the mission, calling it too dangerous for his lightly armed unit, which was given scant intelligence and no armed backup. He was overruled by his commanders.

"If he had been listened to," says Hank Black, "my son and Jeremiah, LaDavid, and Dustin would be here today."

The Army general who led the investigation into the firefight said it was his "solemn responsibility" to the families of the fallen soldiers to be "accurate and transparent." But in exclusive interviews with ABC News, family members say they are outraged and anguished by the military's initial conclusions. The Defense Department has since ordered another review.

Myeshia Johnson, LaDavid Johnson's widow, says her family has been through "so much pain and so much suffering," but won't be able to heal without knowing the full truth. "I feel like they're covering everything up," she says. "Just say what really happened. That's all you have to do."

More about this ABC News Investigative Unit documentary can be found at *abcnews.go.com*. *National Geographic* and ABC News plan to collaborate on future stories.

BY **PETER SCHWARTZSTEIN**
PHOTOGRAPHS BY **ARKO DATTO**

A Great Forest Shrinks, and Lives Are Washed Away

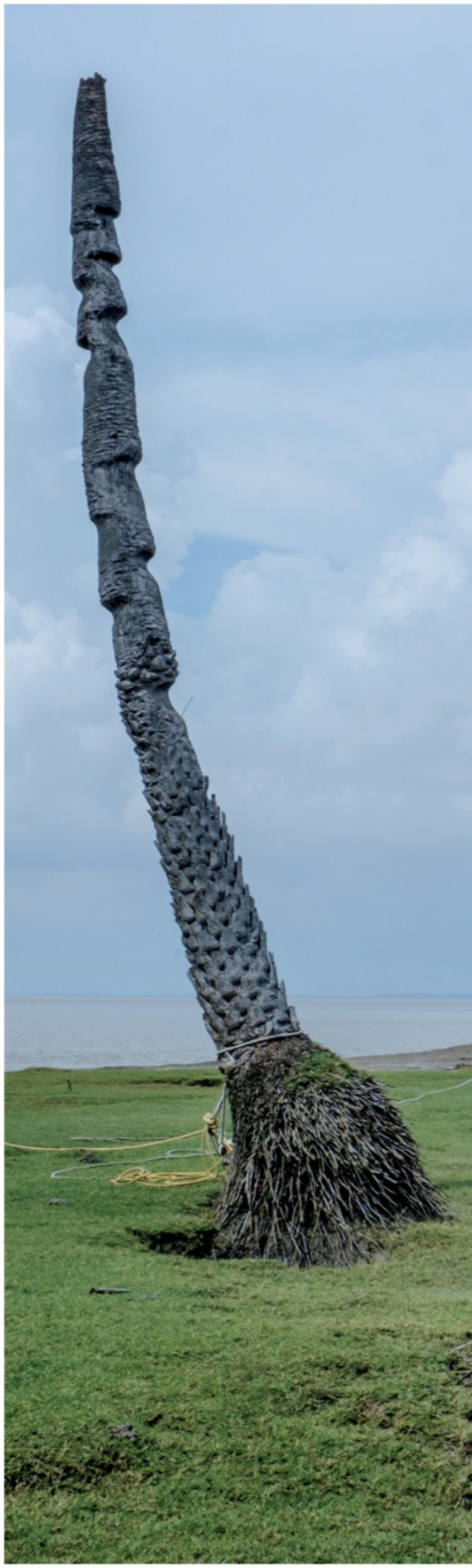
RISING WATERS AND ILLICIT LOGGING ARE KILLING THE TREES THAT PROTECT THE INDIA-BANGLADESH COAST.

It was when the body of a long-dead friend surfaced near her front door that Bulu Haldar knew her house was as good as gone.

For weeks, the embankment shielding East Dhangmari, in the Khulna district of southwestern Bangladesh, had been threatening to sink into the Pasur River. First, a ferocious storm had ripped into the outer layer of concrete. Then, at the end of 2017, the river had begun eating into the porous earthen wall itself. Locals rushed in sandbags, but that bought only a few days' respite. When the river finally surged into the cemetery across from Haldar's garden, disinterring skeletons and contaminating the village's drinking pools, it filled her one-room hut waist-deep in muddy brown water.

"There was nothing else I could do to protect my house," she said. "We were powerless, like children."

Haldar, a meticulously dressed widow of about 50, had at least had some inkling of what was to come. She'd watched as the nearby Sundarbans, a vast mangrove forest that flanks the village, had retreated, its trees looking increasingly weedy. She'd noted how the water appeared to draw strength from the forest's weakness. The only surprise, Haldar insisted, is that the village's earthworks held out for so long. "The trees defended us, but we treated them very badly," she said. "So now we are all suffering the consequences."



Ghoramara Island, India, on the western edge of the Sundarbans mangrove forest, has been robbed of its protective mangroves by tree cutting and sea-level rise and is eroding steadily. Nitya Gopal lost his home.

PREVIOUS PHOTO

Tidal surges now isolate parts of Sagar Island, south of Ghoramara in the Hugli River.

IN BANGLADESH and the neighboring Indian state of West Bengal, there are thousands of villages like East Dhangmari—places that are losing their natural defenses against climate change just as it is intensifying. The land is paper-flat and criss-crossed by rivers bulging with meltwater from the Himalaya. Cyclones frequently roar in off the Bay of Bengal, sometimes killing thousands. Flooding is pervasive.

Some farmers in Bangladesh—a country the size of Iowa with a population of 160 million—refer to their homeland as a divine prank: The soil is fantastically fertile, but you're always in danger of getting washed away. In 1998 an especially monstrous flood inundated about 70 percent of the country.

One thing the region's coastal communities felt they could always bank on, though, is the Sundarbans, the world's largest contiguous mangrove forest. Spanning nearly 4,000 square miles on both sides of the Indian-Bangladeshi border, this dense swamp of flood-tolerant trees stands as a green wall, absorbing storm surges and blunting even the worst cyclones. For villagers, the forest is also an abundant source of honey and its waters a source of fish. "The Sundarbans is our mother," said Joydev Sardar, secretary of the fishermen's association in Harinagar, Bangladesh. "She protects, feeds, and employs us."

But after years of abuse from man and nature, the mangroves seem to be nearing their limits. Illicit logging, mostly for building materials to house the region's booming population, has thinned out the periphery of the forest. At the same time, increasing water salinity caused by the encroaching sea is killing off many higher value, storm-stopping tree species, such as the sundari that gives the forest its name. The salinity assault comes from both land and sea: Upstream dams on rivers in India have reduced freshwater flow into the Sundarbans, while sea-level rise caused by climate change is flushing more salt water into the mangroves.

"The salinity front is just going up and up and up," said Mashfiqus Salehin, a professor at Bangladesh University of Engineering and Technology's Institute of Water and Flood Management. "New areas will salinize, and moderately salinized areas might become unlivable. It's becoming a big problem." In the worst-case scenario, in which sea levels rise by more than six feet this century, Bangladesh alone stands to lose some 800 square miles of mangroves in the Sundarbans. The best-case scenario is a loss of roughly 80 square miles. Salehin and other scientists fear even that much might prove disastrous for a country so poor the forest is besieged by human needs.

The land itself is disappearing. Without the tangled roots of the mangroves to stabilize it, land erodes into the sea—and with upstream dams trapping river sediment, it's not replenished as it once was.

The islands in India's Hugli River, in the Ganges estuary on the western edge of the Sundarbans region, illustrate advanced stages of the decay. At least three islands that a century ago were covered in mangroves—Lohachahara, Suparibhanga, and Bedford—have vanished. Others are eroding fast: Sagar Island has shrunk by about 20 square miles since the mid-20th century, even as its population has swollen with new arrivals from its disappearing neighbors. Crop-growing conditions on Sagar have deteriorated so much that residents now survive largely off seasonal labor elsewhere.

In some parts of the Sundarbans, the sea is advancing about 200 yards a year. "The people around the Sundarbans will lose a lot," said Tuhin Ghosh, an associate professor at Jadavpur University in Kolkata. "This is happening now." But even cities like Kolkata and Dhaka that lie some distance from the vanishing mangroves, he added, will find themselves "extremely exposed to cyclones and storm surges."

IN FEBRUARY 2018 part of the embankment that holds back the Chunar River west of East Dhangmari, Bangladesh, collapsed for the third time in a year. Sixteen houses were swept away in what for locals had become an almost routine tragedy. But as the catalog of misfortunes mounted over the following months, even the oldest, most judicious residents knew these were no ordinary crises. Rice yields during the 2018 dry-season harvest were way down—often well under a ton an acre, which pushed up food prices. In many fields, vegetables simply wouldn't grow in the salty soils.

"Because of the water damage, it sometimes seems like only the carpenters have work," said farmer Bimol Sardar.

In the spring of 2018, a disease that has

Funding for this story was provided by Internews' Earth Journalism Network.

Lost Protection

The Sundarbans spans nearly 4,000 square miles of India and Bangladesh along the Bay of Bengal. The world's largest continuous mangrove forest, it's home to a wide variety of species. For the 7.5 million people who live in the region, the forest is a natural barrier against tides and cyclones. But as people cut the trees and rising seas bring saline waters, the forest and the land itself are shrinking. More than a million coastal residents have already migrated north.

proliferated across some of southern Bangladesh struck this quiet corner of the country. Cholera, thriving in the hotter temperatures and increasingly brackish waters of the Sundarbans, has come roaring back in the swamps in which it was supposedly born. When I visited, the local doctor was overwhelmed.

"Almost every one of my patients is here because of water-related diseases that were nowhere near as much of a problem before," said Shivapada Mondol. "The circumstances are verging on dangerous." On a stretcher outside his office, a skeletally thin old man retched loudly; the man's daughter tried to push more fluids into him.

Finally, as if to illustrate the impossibility of living in the new Sundarbans, several dozen families pulled up stakes in April and moved to Dhaka, the capital of Bangladesh. No longer able to make much of a living off the land, they opted to join the million to 1.5 million other villagers from southern coastal communities who've already relocated to the overloaded city, according to Atiq Rahman, director of the Bangladesh Center for Advanced Studies. The World Bank suggests that by 2050, more than 13 million

CLARE TRAINOR, NGM STAFF. SOURCE: NASA

Day laborers repair earthen flood defenses along the flanks of Sagar Island. Even though cyclones and storm surges are strengthening, death tolls are decreasing as emergency procedures and shelters improve.

Top left: Kishari Mandal grazes her cattle on Ghoramara Island after a tidal surge has receded. **Top right:** On Sagar, Bijoy and Sona Bag and their children stand on ruins of a school that succumbed to tides in 2017. **Bottom right:** A lifeguard patrols off Sagar, where crowds of Hindu pilgrims come to bathe in the Ganges Delta. **Bottom left:** In Bangladesh, Mohammad Giasuddin Hawladar (left) and Mohammad Shobuj Hawladar remain on the crumbling banks of tiny Chalitabunia Island. Many people have fled the increasingly flood-prone Sundarbans.

Bangladeshis—including most of those on the margins of the Sundarbans—might migrate because of climate-related crises. The forecast in West Bengal is similarly alarming.

Despite the challenges, some people here remain guardedly optimistic about the future. The governments on both sides of the border have gotten a grip on the worst of the mangrove cutting, heavily punishing offenders, and they've learned from past natural disasters. By building more cyclone shelters and deploying up to 150,000 volunteers before major storms strike, Bangladeshi officials have drastically cut death tolls. In even the poorest parts of the Sundarbans, villagers have displayed an impressive capacity for adaptation. As salinity surges, they've abandoned rice farming in favor of shrimping.

But in the battle to preserve the mangroves—and in the long run, perhaps Bangladesh itself—the difficulties are increasing. Dhaka has green-lit the construction of a large, Indian-backed, coal-fired power station at Rampal, on the edge of the Sundarbans, a move that could pave the way for other polluting industries. China is proposing more dams in the Brahmaputra basin, potentially jeopardizing the mangroves' remaining freshwater supply. And the climate keeps on changing, bringing ever more erratic rains, storms, and temperature swings.

As the troubles mount, some locals wonder: In the land that mangroves built, will climate change be king?

"The Sundarbans built this country," Bulu Haldar said. "Perhaps the Sundarbans"—or the loss of this forested region—"will destroy it." □

Peter Schwartzstein is an Athens-based journalist who focuses on food, water, and climate. **Arko Datto** works on long-term projects on the Indian subcontinent from his base in Kolkata. This is their first article for the magazine.

BHARAT SEVASHRAM
KOLKATA

YOUR SHOT

SMAHA JAHANGIR

PHOTOS FROM OUR COMMUNITY

WHO

Jahangir, an optometrist in Faisalabad, Pakistan

WHERE

The 125th floor of Dubai's Burj Khalifa, the tallest building on Earth

WHAT

Taken with a Nikon D610 camera with Tamron 15-30mm f/2.8 lens

For her birthday, Jahangir visited Dubai, the United Arab Emirates city famous for its large buildings and bold ambitions. Late one afternoon, tourists filled the observation decks to view the sunset from the 124th and 125th floors of the Burj Khalifa, the world's tallest structure. A young man and woman stood in front of the glass, overtaken by golden light. Jahangir took two shots of them in perfect silhouette. A few seconds later, the young couple broke their position and walked away.

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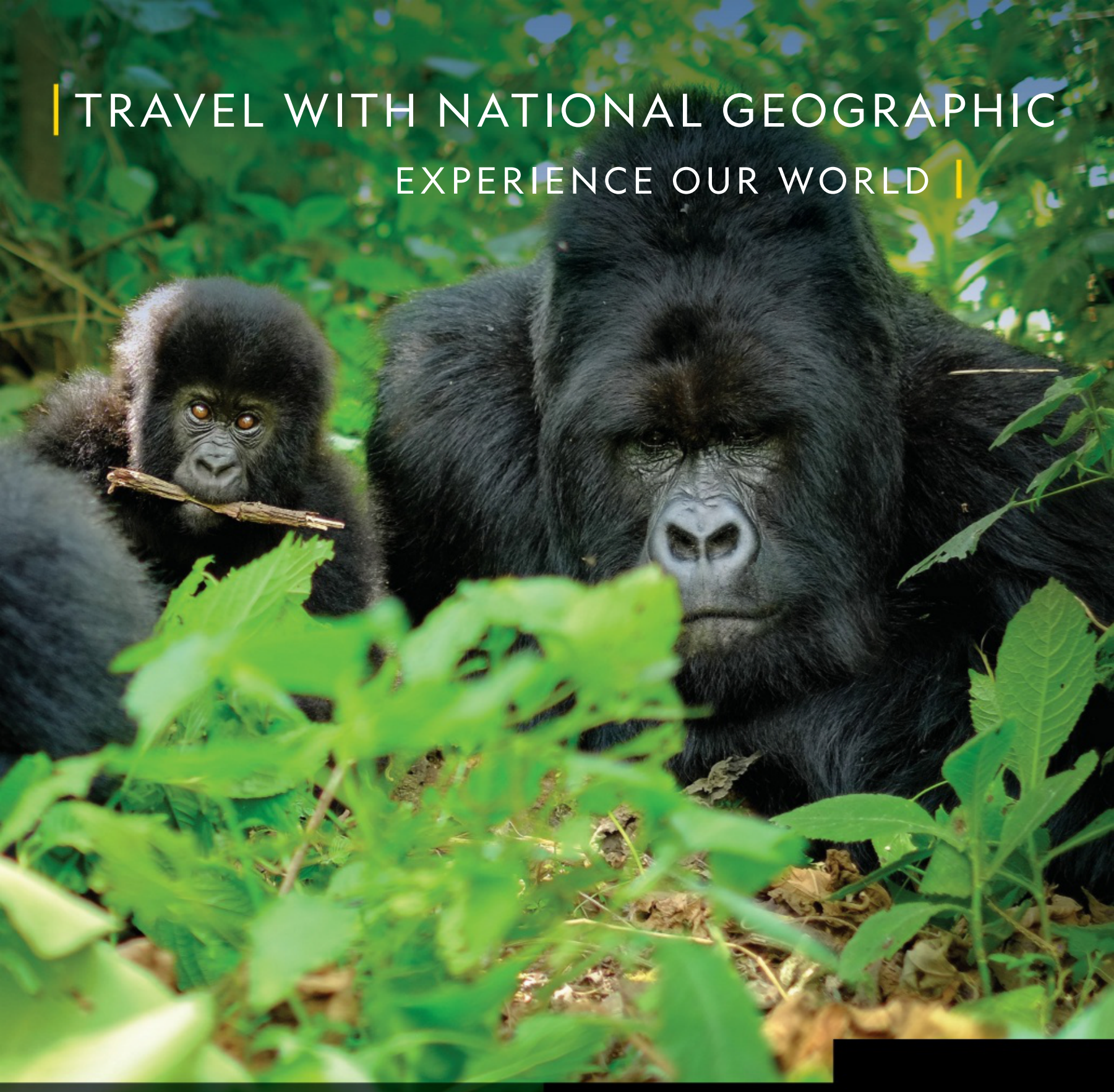

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African White-backed Vulture *(Gyps africanus)*

Size: Body length, approx. 94 cm; wingspan, approx. 2.2 m **Weight:** 4.2 - 7.2 kg **Habitat:** Open woodlands, steppes and savannas of central and southern Africa **Surviving number:** Estimated at 270,000 in 2014

Photographed by Guy Edwardes

WILDLIFE AS CANON SEES IT

Hardly a dainty eater. The African white-backed vulture squeals and squabbles aggressively over its meals as it contends with other vultures. After eating, it retires to a nearby water hole to bathe together with its fellows. The most common vulture in Africa, it breeds in loose colonies on trees. But its numbers are declining at an alarming rate due to loss of habitat, accidental and intentional poisoning, and high demand among traditional healers who use its body parts in witchcraft and juju practices.

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.

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